MEDICAL ELECTRICITY

A PRACTICAL HANDBOOK FOR STUDENTS AND PRACTITIONERS

BY

H. LEWIS JONES, M.A., M.D.

Fellow of the Royal College of Physicians of London; Consulting Medical Officer to the Electrical Department in St. Bartholomew's Hospital; Honorary Fellow of the American Electrotherapeutic Association; Member of the Société Française d'Électrothérapie et de Radiologie; Associate of the Institution of Electrical Engineers

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PREFACE TO THE SIXTH EDITION

SINCE the issue of the last edition of this book a marked change has come over our conceptions of electrotherapeutics. Whereas, in the past, there has been much uncertainty as to the modes of action of electricity on the body, we may now take our stand upon a firmer foundation, and may recognize that electrical applications act either by the chemical (ionic) effects which they produce, or by their thermal effects. This attitude enables us to see more plainly what results may be reasonably expected from electrical treatment, and teaches us how to proceed so as to obtain the results desired.

The subject of X rays in diagnosis has become too large to be fully dealt with in the space available in this volume. Sufficient, I trust, has been given to lead beginners to the stage at which special works must be called for.

H. LEWIS JONES.

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MEDICAL ELECTRICITY

CHAPTER I

FIRST PRINCIPLES AND DEFINITIONS

Electroscopes—Conduction—Electromotive force—Capacity—Condensers—Leyden jar—Theory of Arrhenius—The voltaic cell—Electrolysis—Anions and kathions—Resistance—Ohm's law—Units of measurement—Primary and secondary cells—Magnetic field—Galvanometers—Electromagnetic induction—The induction coil—The dynamo-machine—Alternating currents—The transformer.

1. **Introductory.**—For the proper use of electricity in medical treatment, the practitioner requires a sound knowledge of the elementary principles of the science of electricity, and this should be sought for in one of the textbooks of the subject—as, for example, that of Professor Silvanus Thompson. In this chapter certain points which are necessary as an introduction to what follows will be briefly mentioned.

2. **Gilbert of Colchester.**—The foundation of the modern science of electricity was laid by a medical man—Dr. Gilbert, of Colchester, Physician-in-Ordinary to Queen Elizabeth, and President of the Royal College of Physicians in the year 1600, the date of the publication of his treatise "De Magnete."

He extended to a large number of other substances the ancient observation that rubbed amber attracted light bodies. It seems, also, that we owe to him the word electricity, for he called all those substances electrics which, when rubbed, displayed the same attractive power for light bodies as amber (ἤλεκτρον, electrum) does, and soon afterwards the word electricity was introduced to indicate this power considered as a quantity capable of measurement.

All bodies, when rubbed with suitable precautions, are, to use

Gilbert's term, *electrics*—that is to say that whenever any two bodies are rubbed together electrical separation occurs, one body becoming positively and the other negatively electrified, although in many cases it is difficult to observe this, owing to the escape of the charge. In fact, it is possible to arrange all substances in a list, such that when any pair of them is rubbed together the body higher in the list is positively electrified, while the other is negatively electrified to an equal extent.

Such a list is as follows: Cat's fur, flannel, glass, silk, shellac, ebonite, sulphur. Thus, glass rubbed with silk will be positively electrified, and ebonite or resin rubbed with silk is negatively electrified.

Positively electrified bodies repel each other, and negatively electrified bodies repel each other, but a positively electrified body and a negatively electrified body attract one another.

3. **Hypothesis of Fluids.**—Various hypotheses have been put forward to account for this action. In the "one-fluid" theory, which was put forward by Franklin in 1750, bodies that were positively electrified were looked upon as containing an excess of electric fluid, and bodies that were negatively electrified were looked upon as suffering from a deficiency, while all bodies in the normal neutral state were looked upon as having neither an excess nor a deficiency. The "two-fluid" theory of Symmer, proposed in 1759, assumes that all matter contains an inexhaustible supply of a so-called electric fluid, which is capable of being split up, by friction or otherwise, into equal quantities of two fluids of opposite properties—viz., the so-called vitreous (positive) and resinous (negative) electricities—and bodies that display the signs of electrification are said to be charged with one or other of these fluids. This hypothesis gives us, in many cases, a convenient method of expressing the facts. It is an essential part of the hypothesis that both fluids shall always be produced in equal quantities.

To-day the electron theory supposes that the actual material of electricity is the electron, a particle one thousand times less than a hydrogen atom. The electron is negative electricity, and every atom of matter is said to contain one or more electrons, which can be separated from the atom and set in movement, the movement of the electrons being the electrical current. A body which is negatively electrified has an excess of electrons; a positively charged body has a deficiency. The atom of positive

electricity is not yet known, so that we are at present accepting a sort of Franklinic theory, but modified, in the sense that it is negative electrification which constitutes the excess of charge, and positive electrification which constitutes the deficiency, and we say that a glass rod rubbed with silk is positively electrified because the silk withdraws electrons from the glass. Sir Joseph J. Thomson, in his researches into the nature of the discharge of electricity through gases, came to the conclusion that the conveyance of electricity in highly exhausted vacuum tubes took place by means of negatively charged particles moving at an enormous velocity from the negative electrode. These particles, to which he gave the name of "corpuscles," he showed to have a mass less than one-thousandth of the mass of a hydrogen atom, and to consist of negative electricity alone, quite apart from matter, and he states the position as follows, if we substitute the word "electron" for "corpuscle": "These results lead us to a view of electrification which has a striking resemblance to that of Franklin's "one-fluid" theory of electricity. The electric fluid of Franklin corresponds to an assemblage of electrons, negative electricity being a collection of these electrons. The transference of electrification from one place to another is effected by the motions of electrons from the place where there is a gain of positive electrification to the place where there is a gain of negative. A positively electrified body is one that has lost some of its electrons."*

4. **Conduction.**—If an electrified body, insulated by being supported by silk strings or by a glass stem, be connected with another similarly supported non-electrified body by means of a wire for an instant, the second body will become electrified in the same sense as the first body, but to a less degree, the charge of the first body being conducted along the wire connection, and divided between the two bodies. If the connection had been made with a glass rod, a stick of resin, or a silk thread, no transfer of charge would have occurred. The metal wire is, therefore, a *conductor* of electricity, the glass rod, etc., are not.

Substances vary very much in their power of conducting electricity. Thus, metals are good conductors, saline solutions and living bodies are less good; wood and cotton are poor conductors; while wool, silk, oils, resins, ebonite, air at ordinary

* From "The Electron Theory," by E. E. Fournier d'Albe. Longmans, Green and Co., 1906.

pressure, and most kinds of glass, conduct so slightly that they are used as insulators.

At low barometric pressures air and gases conduct fairly well, and it will be seen hereafter that under certain special conditions a gas may conduct even when not rarefied.

The processes concerned in the conduction of electricity are not identical in all classes of conductors. Sir Oliver Lodge,* in a valuable address delivered before the Section of Electrotherapeutics and Radiology at the Annual Meeting of the British Medical Association held in Birmingham in 1911, has expressed this by saying that in metals the electrons travel through the atoms of matter, in liquids they travel with the matter; in gases they travel free, or without the matter. "In the metal," he says, "they flow through it like heat, and the old fluid theory of electricity which was laughed at has, nevertheless, a good deal of truth in it. But when the electrons come to the edge of the metal some difference has to be made. They may rush out free, or, as in the case of the liquid, they may carry the atoms with them, and give the phenomenon of electrolysis."

5. **Induction.**—A conductor can not only be electrified by a transfer of electricity between it and another conductor, but also by an alteration in the distribution of the electricity on its surface, without any transfer of electricity between it and another conductor. In the former case the body is said to be electrified *by conduction*, in the latter *by induction* (electrostatic induction).

Induction effects are produced whenever an electrified body is brought near any other body, and we may say, in the language of the two-fluid theory, that an electric charge in any body disturbs the equilibrium of the neutral fluid in the bodies near it, attracting an equal quantity of the fluid of opposite sign to their nearer sides, and setting free an equal quantity of the fluid of similar sign to itself at their remoter ends. On the removal of the inducing body, the induced charges recombine and disappear. If before the removal of the inducing body the conductor be touched with a finger, or otherwise be connected for a moment to earth, then that component of the induced charge, which is of like sign with the inducing charge, and is repelled, will escape by the channel so provided for it, and the subsequent

* "Conveyance of Electricity through Solids, Liquids, and Gases, and the Production of Radiation," *British Medical Journal*, October 14, 1911.

withdrawal of the inducing body will therefore leave the other body charged with a charge of the opposite sign.

6. **Electroscopes.**—The simplest means by which we may tell when a body is electrified is an instrument called an electroscope. The usual form of electroscope is that known as the gold-leaf electroscope, which is made of two strips of gold-leaf hung together from a wire. When these are electrified, they repel each other and diverge, and so indicate the presence of electrification. The instrument is usually enclosed in a glass case, which serves as an insulating support, and protects the gold-leaves from disturbances by currents of air (Fig. 1). This figure represents a simple form of electroscope, but many elaborated and improved forms have been devised.

With this instrument one can also discern the sign of the charge on an electrified body, for if a portion of the charge be

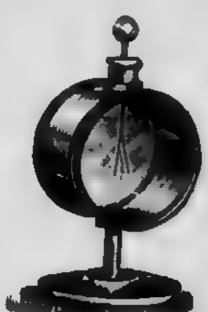


FIG. 1.—GOLD-LEAF ELECTROSCOPE.

transferred to the electroscope, and an additional charge be added from a positively electrified body—*e.g.*, from a glass rod that has been rubbed with silk—then, if the former charge was negative, the leaves will collapse, but if positive, they will diverge still further.

The best way of carrying out this test is as follows: Approach the charged body to the electroscope. It becomes charged by induction, and the leaves will diverge. Touch the knob of the electroscope with the finger for an instant, and they will collapse; but on subsequently removing the body to be tested, they will again diverge under the effects of a charge of opposite sign to that of the body to be tested. Now bring up near the electroscope the rubbed glass rod. If the leaves collapse, the present

charge is negative, and that of the original charged body was therefore positive.

7. **Electric Quantity.**—Hitherto electrification has been spoken of rather as a state or quality induced in bodies by certain processes. It is now necessary to arrive at a definite conception of this state as a measurable quantity.

This electricity, then, is of two kinds—one named positive, say, a deficiency of electrons; and one negative, say, an excess of electrons. It has been seen already that positive electricity repels positive, and that negative repels negative, while positive electricity attracts negative, and *vice versa.* This has to be expressed in terms of some unit, to be chosen once for all.

Maxwell ("Electricity and Magnetism") gives the following definition: "*Unity of Quantity.*—That quantity of electricity which, when supposed collected at a point, will repel an equal quantity of similar electricity collected at a point, and placed at unit distance from the first, with unit force, shall be taken as the unit quantity of electricity."

In this definition the unit quantity of electricity is made to depend on the units of length and of force, and this latter is defined with reference to the units of length, mass, and time. Hence the unit quantity of electricity can be completely defined in terms of the units of length, mass, and time. For scientific purposes these are taken as 1 centimetre, 1 gramme, and 1 second respectively.

In thus defining the unit quantity of electricity, the medium in which the action between the two charges takes place must be taken into consideration. It is assumed, however, that this is either dry air or, more precisely, a vacuum.

The attraction or repulsion between two quantities of electricity is proportional to each—*i.e.*, is proportional to the product of the two quantities. It is also inversely proportional to the square of the distance between them, always, of course, supposing that the two quantities are collected at two points.

8. **Electromotive Force, Potential.**—Whatever produces, or tends to produce, a transfer of electrification, is called *electromotive force,* and this is often written E.M.F. for brevity's sake. Thus, when two electrified conductors are connected by a wire, and when electrification is transferred along the wire from one to the other, the tendency to this transfer, which existed before the introduction of the wire, and which,

when the wire is introduced, produces this transfer, is called the electromotive force from the one body to the other along the path marked out by the wire. If the potentials at different points of a conductor are different, there will be an electric current from the places of high to the places of low potential. The idea of electrical potential may be illustrated by comparing it with pressure in the theory of fluids and temperature in the theory of heat. If two vessels containing fluids are put into communication by means of a pipe, fluid will flow from the vessel in which the pressure is greater into that in which it is less till the pressure is equalized. Again, if two bodies at different temperatures are placed in thermal communication, either by actual contact or by radiation, heat will be transferred from the body at the higher temperature to the body at the lower temperature till the temperature of the two bodies becomes equalized. Similarly, when two electrified bodies are put into electric communication by means of a wire, electrification will be transferred from the body of higher potential to the body of lower potential.

9. **Electrometers.**—The only thing that can be observed in connection with electricity at rest is a difference of potential. It is possible to measure the quantity of electricity driven through certain instruments just in the way that a quantity of water driven through a water-meter can be measured, and some of these instruments will be discussed in a later paragraph; but for the present we can only appreciate electrical charge by observing a difference of potential, and electroscopes and electrometers are instruments for showing or measuring differences of potential.

The gold-leaf electroscope has been shortly referred to above. The divergence of the leaves of this instrument may be taken as an indication that the knob or disc, or way by which electricity enters the instrument, is at a different potential to its surroundings; but obviously it does not give us more than the roughest indication of the amount of difference of potential. In cases where there is a great difference of potential a delicate gold-leaf electroscope is likely to be spoilt by the violent repulsion of the leaves, so rougher forms may be used—*e.g.*, leaves of thin aluminium or even pith balls suspended by linen threads may be used instead of the more delicate gold-leaf.

If it is required to measure a difference of potential, an electro-

meter must be used. There are many forms of these, and descriptions of some of them and of the modes of using them will be found in most textbooks.

10. **Distribution of Charge—Density.**—It has been proved by direct experiment in many ways that the whole of an electric charge resides on the surface of a charged conductor. It is found that while the distribution over a sphere is uniform, as might be expected from the symmetry of the figure, it is not so on conductors of other shapes. On these the charge per unit of surface, which is called the density, is greater the greater the curvature of the surface, till at a sharp edge or a point the density becomes so great that at high potentials a discharge takes place. For this reason if a point is attached to a highly-charged conductor a stream of charged particles of air is repelled from the point, giving rise to a wind setting from the point and rapidly discharging the conductor. This action of points becomes of great importance in some electrical machines, and in some kinds of electrical treatment. In the first place, the presence of a point on a charged conductor at a high potential renders it difficult to keep a charge on the conductor, however well it may be insulated. But the same effect will occur if a point be presented to a charged conductor ; for the charge, which we will suppose is positive, of the conductor acting inductively on the point will induce a negative charge at the point, the density of which will become so great that it will be discharged to the original conductor, neutralizing its positive charge, and leaving the conductor which bears the point positively charged if it is insulated. It is by this action that the prime conductors of statical machines are charged from the excited plate or other movable part.

11. **Capacity.**—The quantity of electricity that is required to raise the potential of any conductor from zero to unity, all other conductors in the neighbourhood being kept at zero potential, is the measure of its *Capacity.*

As the charge resides only on the surface of a charged body, the capacity of a conductor is determined by the extent of its surface, and a body of a large surface has a larger capacity than a body of smaller surface.

When a conductor is said to have a given capacity it must not be thought that the conductor can hold only a certain fixed charge, in the way in which a glass bottle can be said to hold only so much water, because the quantity of electricity that can

be put into a conductor of a certain capacity depends upon the potential or pressure at which it is charged. A body of unit capacity holds unit quantity when charged to unit potential, and holds ten times as much when charged to ten times the potential. On this account it is necessary to know both the capacity of a conductor and the potential to which it has been charged before forming any idea of the quantity of electricity which it contains. The capacity of a conductor may be compared to the capacity of an elastic bag. The amount of air or of water that can be forced into an elastic bag of given size depends upon the pressure at which it is forced in, and provided the bag does not burst it can be made to hold more and more by increasing the pressure at which it is charged.

The capacity of a conductor is increased by bringing near to it other conducting bodies, which are maintained at zero potential by being connected to earth, and the nearer the "earthed" conducting bodies are to a conductor the greater becomes the capacity of that conductor. This is an effect of induction (§ 5).

The importance of this point is well brought out by an example. The capacity of a sphere of 10 centimetres radius suspended freely in space is 10 units, but if another sphere of 11 centimetres radius be placed concentrically to it, so that the two spheres are separated one from another all round by 1 centimetre of air, and if the outer sphere be maintained at zero potential by connection to earth, then the capacity of the inner sphere is no longer 10 but 110 units, while if the radius of the outer sphere be reduced to 10½ centimetres, the capacity of the inner one would become 210 units.*

12. **Condensers.**—An apparatus consisting of two insulated conductors, each presenting a large surface to the other, with a small distance between them, is called a condenser, because when one conductor is connected to earth a small electromotive force is able to charge the other with a much larger quantity of electricity than if it stood alone—*i.e.*, its capacity is increased by the proximity of the other conductor.

The simplest form of conductor consists of two metallic discs supported on insulating stems, and facing each other, the intervening non-conductor or *dielectric* being air. If, now, a different

* If a be the inner and b the outer sphere, then the capacity of a is given by the formula $\frac{ab}{b-a}$.

dielectric, as, for example, a sheet of glass, be inserted instead of air, the capacity of the condenser will be found to be different, and greater than before; thus the action across the dielectric depends on the nature of the dielectric, and since a glass condenser is found to have a higher capacity than an air condenser, glass is said to transmit induction better than air, or, in other words, glass is said to have a higher *specific inductive capacity* than air.

13. **Leyden Jar.**—The electrical condenser most often used in experiments on static electricity is that known as the Leyden jar (Fig. 2).

The ordinary form of this apparatus is a glass jar or bottle, coated inside and out with metal foil to within 2 or 3 inches of

FIG. 2.—LEYDEN JAR.

the top. Through the cork of the bottle a wire passes, terminating above in a knob and below in a chain, to insure metallic contact with the inner coating. To charge the jar, the outer coating is connected to earth, and so kept at zero potential, while the inner coating is connected with the conductor of an electrical machine. The charge given to the inner coating acts inductively upon the outer coating across the dielectric of the jar, and its capacity is large in proportion to its size. The jar or condenser may be discharged by bringing a metallic conductor, which is in connection with the outer coating, near to the knob of the jar. A spark will occur, and the jar is discharged.

The capacity of a Leyden jar depends upon the area of the surfaces coated with tinfoil, and also, from what has been said in § 11, upon the thinness of the glass of which it is made. If

the glass be very thin it may give way under the strain when charged to a high potential, and be broken to pieces.

Condensers are also made by pasting a sheet of tinfoil on each side of a pane of glass, or by arranging a number of sheets of glass and tinfoil alternately. The even numbers of the tinfoil sheets are connected together to form one armature of the condenser, the odd numbers forming the other. Condensers are used by connecting one coating or armature to one pole of an electric source, and the other to the other pole, or to earth.

Instead of the glass sheets shellac-varnished paper may be used as the insulator or "dielectric," and owing to its thinness a large capacity can easily be obtained in this way; but the tendency of the thin paper to be perforated if high electromotive forces are applied to it should be borne in mind.

The discharge phenomena of a Leyden jar present many points of interest, and will be found to have important applications in some forms of medical apparatus. Generally the discharge takes place by a series of oscillations, which may be compared to the movements of a piece of watch-spring, or of an elastic rod which has been bent aside and allowed to fly back into its original position. The watch-spring, under these circumstances, swings to and fro several times before coming to rest.

In the case of the Leyden jar discharge, it will be found that the rate or "frequency" of its oscillations can be varied by varying the electrical dimensions of the Leyden jar or condenser, and those of the circuit through which the discharge takes place.

14. **Current Electricity.**—At the end of the eighteenth century Volta observed that when dissimilar metals, such as zinc and copper, were brought into contact in air electrical separation took place, and a small difference of potential (§ 8) could be observed between the metals, the zinc being positive to the copper, or at a higher potential. Under these circumstances this difference of potential does not efface itself by discharging across the junction of the two metals, as a difference of potential between two parts of a homogeneous conductor would do, because the electromotive force set up at the junction of the two metals could only discharge itself across the junction by a flow in the opposite direction to that in which it tends to cause a flow; but that is absurd. But if the two pieces of metal, while in contact, are immersed in some liquid that is capable of acting chemically on one of them—*e.g.*, dilute sulphuric acid—a "circuit" is formed,

and the discharge can take place through the liquid, with the manifestation of changes therein, and a continuous discharge or current takes place round the circuit in the following way :—

Positive electricity passes across the junction from the copper to the zinc, and then from the zinc through the liquid to the copper again. If the connection of copper to zinc be by a wire, as is usually the case, we may look on the junction as a sort of pump driving positive electricity round the circuit, so that it passes from the zinc across the liquid to the copper, and back to the zinc again, along the metallic connection between it and the copper, thus making a true circuit.

Such an arrangement is called a voltaic cell, and will give a continuous flow of electricity or current, till either the zinc or the exciting liquid (called the *electrolyte*) is exhausted.

15. **Solution and Osmotic Pressure.**—The difference of potential in a cell, or its *electromotive force*, was formerly thought to be due to the contact electromotive force of the metals forming the poles of the cell, though in certain cases this might be slightly modified by the liquid used. This view has recently been examined again in the light of the fresh evidence which has been brought forward, in particular by the work of Van 't Hoff and Arrhenius. From their researches it seems probable that among the causes of the electromotive force of a cell the "contact E.M.F." of dissimilar metals occupies a minor place, while the phenomena occurring in the solution or electrolyte are of greater importance. The arguments in favour of this view may be found very clearly stated in McMillan's "Treatise on Electrometallurgy,"* from which the subjoined summary has been prepared, while those who wish to go more deeply into the matter should consult "The Elements of Electrochemistry," by Max Le Blanc.†

Briefly stated, the steps in the line of reasoning are as follows :

(*a*) *Solution Pressure.*—The tendency of a body to go into solution when placed in a solvent may be called its solution pressure, and the different degrees of solubility presented by different salts, which are very varied, may be spoken of as differences in their solution pressures.

The solution pressure of any particular body is constant under any given set of conditions, but varies definitely with any definite change in these conditions.

* Griffin and Co., London, 1910.

† Macmillan and Co., London, 1896.

(*b*) *Osmotic Pressure.*—When a soluble substance is placed in water, it goes into solution, at first rapidly, but as the solution approaches saturation it dissolves more and more slowly. The dissolved molecules appear to exercise a pressure which opposes the solution pressure, and eventually a point of equilibrium is reached when the opposing pressure of the dissolved particles equals the solution pressure of the substance. This back pressure is known as osmotic pressure, and is susceptible of accurate measurement.

We may take as a concrete example the behaviour of zinc sulphate and distilled water. At 20° C. 53 parts of zinc sulphate will dissolve in 100 parts of water—that is to say, the solution pressure of the salt enables it to dissolve in the water to that extent. At 50° C. 66·9 parts will dissolve. At these temperatures the solution pressure of the zinc sulphate is balanced by the osmotic pressure of the solutions, when those proportions of the salt are present in solution in the water. If the warmer solution be cooled, the equilibrium will be disturbed, the osmotic pressure will become stronger than the solution pressure, and solid zinc sulphate will be deposited from the solution. Conversely, if the cooled solution be warmed, its osmotic pressure will be reduced, and more of the salt will go into solution.

16. **Theory of Arrhenius.**—The behaviour of solutions when they are traversed by electrical currents is more easily understood if it is assumed that the whole class of compounds known as electrolytes break up, or are dissociated, when dissolved in water. An electrolyte is a substance whose constituents are separated when it is traversed by an electric current. Almost all chemical compounds are electrolytes, especially the mineral acids, alkalies, and their salts, and also many organic salts of analogous composition. We may believe that sodium chloride, for example, breaks up more or less completely into the two separate parts, Na (sodium) and Cl (chlorine). Hydrochloric acid dissociates into H and Cl, zinc sulphate into Zn and SO_4, and so on, each molecule forming two separate entities, which are known as ions. The ions carry definite charges of electricity, those of the metals having positive charges, and those of the non-metals (chlorine, acid radicals, and the like) having negative charges. The ions, SO_4, Cl, H, Na, etc., do not manifest the chemical properties of their elements as ordinarily recognized. The difference is one of their electrical charges, and when the

ions are deprived of their charges the atom or molecule reappears in its ordinary form. In the solution the ions are equally diffused, and the positive electricity of the one set exactly neutralizes the negative electricity of the other set, so that the dissociation of a salt does not affect the apparent electrical condition of the solution.

The word "ion" means a moving particle, and was first used by Faraday to explain the phenomena observed during the passage of electrical currents through liquids, and particularly the accumulation of certain constituents of the liquids in the neighbourhood of the poles immersed in the liquids. The properties of ions have a special interest in medical work, because the conduction of electricity in the human body is entirely ionic in nature. This theory of dissociation of electrolytes when dissolved is known by the name of the Swedish physicist Arrhenius, and it supplies the best working explanation of the phenomena of the conduction of electricity by watery liquids. Pure water contains practically no ions at all, and is therefore a nearly perfect insulator, but it has a remarkably high power of splitting up the molecules of other substances into ions, and the degree of dissociation of a salt in solution in water is greater for more dilute solutions. Fournier d'Albe * mentions that if water contains 0·0036 per cent. of hydrochloric acid, then 99 per cent. of all the acid molecules will always be dissociated or ionized into H and Cl, while the remaining 1 per cent. will be present as HCl. In the solution there will also be a continual recombination and dissociation going on, so that for every second that the ions spend in combination they spend one minute and thirty-nine seconds in separation.

17. **Electrolytic Solution Pressure.**—In the case of a metal immersed in an electrolyte a phenomenon just like that referred to in § 15 can be observed. The metal tends to pass into solution, and to form ions. Thus we may speak of the electrolytic solution pressure of a metal, to distinguish it from the simpler solution pressure of salts. Just as osmotic pressure opposes solution pressure, so it opposes electrolytic solution pressure. In the case of a metal immersed in solutions of its own salts the osmotic pressure of the ions of the metal already in solution tends, in proportion to their number, to prevent the passage of fresh ions of the same kind into solution.

* *Vide supra*, § 3.

The electrolytic solution pressures of different metals—that is to say, the tendency of different metals to form ions when in contact with a liquid—varies very greatly for the different metals.

When ions are formed in the case of zinc immersed in an electrolyte they acquire definite positive electrical charges, and consequently the liquid becomes positively charged; and as both kinds of electricity must be simultaneously developed whenever electrical energy comes into existence, an actual negative charge is developed on the metal. Electrical equilibrium is thus maintained, while the tendency of the metal to continue forming positive ions is opposed.

Tables have been drawn up of metals arranged in order according to their tendency to form ions, and from the point of view of their action when used as the metals of a voltaic cell they may be divided into those whose electrolytic solution pressure is greater than that of hydrogen, and those others whose electrolytic solution pressure is less.

An abbreviation of such a table would be:

Zinc.
Iron.
Lead.
Hydrogen.
Copper.
Silver.
Platinum.

Those metals whose electrolytic solution pressure is greater than that of hydrogen are able to deprive hydrogen ions of their positive charges, and thus to displace hydrogen in an electrolytic cell. They are the metals which dissolve in acids with evolution of hydrogen gas.

18. **Voltaic Cell.**—If the voltaic cell be now considered as an electrolyte, H_2SO_4, in which the two dissimilar metals, zinc and copper, are immersed, it will be seen that each will exert its own solution pressure, and will become negatively or positively charged. The zinc, by virtue of its high electrolytic solution pressure, tends to form positively-charged zinc ions, and in doing so becomes negatively electrified. The copper has almost no tendency to become ionized, and acquires a positive charge not

directly from the zinc ions but from the hydrogen ions which are displaced by the zinc.

On joining the two metals by a wire, an electrical system or circuit is formed, and a current flows along the wire from the copper to the zinc. The zinc forms positively charged zinc ions, the hydrogen ions give up their positive charges to the copper plate, and pass out of the ionic state to appear at the surface of the copper in the form of bubbles of hydrogen gas; the SO_4 ions migrate towards the zinc plate, and enter into combination with the zinc ions there. So long as zinc ions continue to go into solution, and hydrogen ions continue to give up their charges of positive electricity to the copper, the current of electricity flowing in the wire from copper to zinc will continue;

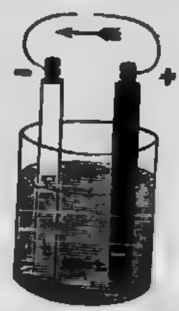


FIG. 3.—VOLTAIC CELL, SHOWING DIRECTION OF FLOW INSIDE AND OUTSIDE.

but as the liquid becomes richer in zinc ions, their osmotic pressure will begin to oppose the electrolytic solution pressure of the zinc, and the action of the cell will fall off.

Another explanation of the action in the voltaic cell is given by Fournier d'Albe in terms of the electron theory. He says: "Take the case of an elementary galvanic cell consisting of a plate of copper and a plate of zinc immersed in dilute sulphuric acid, and joined by a wire outside the liquid. The liquid consists of water molecules, acid molecules H_2SO_4, positive ions H, and negative ions SO_4. Zinc atoms are constantly going into solution, and giving up their electrons to the zinc from which they issue. These electrons, flowing round the outside circuit into the copper, neutralize the H ions in the neighbourhood of the copper, and liberate the hydrogen from the liquid in the form of bubbles. Thus zinc disappears into the liquid on one side, and hydrogen leaves the liquid on the other side."

In any case, whatever may be the terms employed to describe it, the essential feature of the voltaic cell is that there is an expenditure of zinc and a liberation of energy. This liberation of energy at the expense of the zinc takes place whenever zinc is dissolved, but in the voltaic cell we have a contrivance for intercepting the energy set free by the chemical action, and for utilizing it as a current of electricity in the wire circuit joining the poles of the battery.

It is customary to consider the zinc plate of a battery as the positive plate, and the copper or other plate as the negative plate, while the terminal attached to the zinc plate is called the negative pole, and that attached to the copper the positive. The origin of this very confusing nomenclature is, no doubt, the fact that in the liquid the positive direction of flow of the current is from zinc to copper, and because the chemical action takes place at the zinc plate. But in the connecting wire the positive direction of the flow of current is from copper to zinc (see Fig. 3), and, as this is the portion of the circuit that we are most concerned with, the word positive will be used to denote the pole belonging to the copper plate of the battery.

19. **Electrolysis.**—We have seen in the preceding paragraphs that the solution of a salt in water leads to its dissociation into ions. This dissociation is incomplete except at stages of great dilution, but nevertheless we can regard all such solutions as containing free ions abundantly. A solution containing free ions acts as a conductor; indeed, the conductivity depends upon the presence of free ions, and a liquid conducts electricity well or badly in proportion to the degree to which it is dissociated, or (which is the same thing) to the number of free ions which exist in it. Water, for instance, conducts very badly when pure, and it has been calculated that its dissociation is very slight indeed.

The ions in an electrolyte through which no current of electricity is passing have no definite arrangement in the liquid so far as we know. Whatever motion there may be among them has no uniformity of direction, or at least has no tendency to any separation or sorting out of the positively and negatively charged ions.

If an electric current be produced in an electrolyte, as can be done by dipping into it two electrodes which are connected respectively to the positive and negative poles of a source of electricity, an orderly motion of the ions is brought about, and

decomposition of the electrolyte takes place. The negatively-charged ions will move towards the positive pole, and on reaching it they will give up their charges to the pole and lose their existence as ions, and the positively-charged ions will do the same at the negative pole. Thus with hydrochloric acid as the electrolyte, gaseous hydrogen and chlorine separate in "unelectric"* form at the electrodes, the hydrogen at the negative electrode or kathode, and the chlorine at the positive electrode or anode.

The course of events is, however, not always so simple as in the instance just given. Even in that case it would be necessary to employ as the anode of the cell a substance whose electrolytic solution pressure was extremely small. Otherwise no chlorine would be liberated in the gaseous form, for the positive charges supplied to the anode from the external circuit would be expended, not in neutralizing the negative charges of the chlorine ions, but in supplying positive charges to ions of the metal of the anode, which would accordingly enter the solution in the ionic condition, and would exist there side by side with the chlorine ions, whose negative charges would thus be balanced by the positive charges of the newly-formed metallic ions. In the case of an electrolyte of sulphate of copper with metallic copper electrodes the passage of the current causes the copper ions in the electrolyte to move towards the kathode, and there to give up their charges and to appear as metallic copper, while at the anode copper ions are formed at the expense of the copper electrode, and pass into the electrolyte; the effect, therefore, is the transport of copper from the anode to the kathode, and the latter gains while the former loses weight. The SO_4 ions associated with the copper in the electrolyte migrate towards the positive pole, and as the action continues they tend to become concentrated in that part of the solution.

If the electrolyte be a solution of a salt of an alkali metal, as, for example, sodium sulphate, and the electrodes be of platinum, the effects produced by the passage of a current again seem different, and t·'s is on account of certain secondary "reactions." Suppose such a solution, to which some litmus has been added, be electrolyzed, on the passage of the current gases will be evolved at both poles, and the litmus will show the presence of

* Le Blanc, "Electrochemistry," chapter iv., "The Migration of the Ions." Macmillan and Co.

acidity at the anode and alkalinity at the kathode. The gas evolved at the kathode is hydrogen, that at the anode oxygen, and the explanation given is as follows :

The electrolyte contains free sodium ions and free SO_4 ions, some undissociated sodium sulphate molecules, also a few H and OH ions from the dissociation of the water, which occurs only to a very slight extent. During the passage of the current the sodium ions migrate towards the kathode, part with their charges, and deposit sodium in the metallic form. Sodium, however, is decomposed by contact with water into sodium hydrate and hydrogen ; accordingly hydrogen gas is evolved, and the liquid near the kathode becomes alkaline from the dissolved sodium hydrate. At the anode the SO_4 ions also lose their charges, and the SO_4 undergoes a secondary reaction with the molecules of water present to form H_2SO_4 (sulphuric acid) and oxygen, which is evolved. Objections have been raised to this explanation of the events, but it seems very likely that sodium is really set free in the form of metal at the kathode, because if mercury be used as the kathode the evolution of hydrogen is decreased, and metallic sodium can be extracted from the mercury by suitable treatment.

20. **The Laws of Electrolysis.**—The amount of ions deposited by the passage of a current through an electrolyte was shown by Faraday to be connected by a simple relation with the quantity of electricity which passes through the electrolyte ; and he enunciated the following "laws of electrolysis" : (1) The quantity of an electrolyte decomposed by the passage of a current of electricity is directly proportional to the quantity of electricity which passes through it. (2) If the same quantity of electricity passes through different electrolytes, the weights of the different ions deposited will be proportional to the chemical equivalents of the ions. Thus, if the same current passes through a series of electrolytes from which it deposits as ions hydrogen, oxygen, silver, and chlorine, then for every gramme of hydrogen deposited, 8 grammes of oxygen, 108 grammes of silver, and 35·5 grammes of chlorine will be deposited.

The quantities by weight of various substances which are liberated by one unit of electricity (taken as one ampère for one second) are termed the electro-chemical equivalents of those substances. The electro-chemical equivalent of hydrogen is slightly greater than 0·01 milligramme, and of silver 1·118 milli-

grammes. Tables of electro-chemical equivalents are given in the textbooks under the subject of electro-chemistry, and they may be calculated for any ion by multiplying the chemical equivalent of the ion by 0·0103, which is the electro-chemical equivalent of hydrogen.

Elements which form two series of salts, such as copper, which forms cuprous and cupric salts, or iron, which forms ferrous and ferric salts, have different electrochemical equivalents, according as they are deposited from solutions of the cuprous or cupric, ferrous or ferric salts. The electrochemical equivalent of iron from ferrous salts (diad) is 0·2898 milligramme, and from ferric salts (triad) 0·19 milligramme; of copper the weight is 0·652 milligramme from a cuprous salt, and half of that from cupric salts. The electro-chemical equivalent of zinc is 0·338 milligramme.

Sir Oliver Lodge, in discussing conduction in liquids, says that "we learn from electrolytic conduction that every atom carries a certain definite charge or electric unit, monads carrying one, diads two, triads three, but never a fraction; that in liquids these charges are definitely associated with the atoms, and can only be torn away from them at the electrodes; that the current consists of a procession of such charges travelling with the atoms, the atoms carrying the charges, or the charges dragging the atoms, according to the point of view from which we please to regard the process."

21. **Ionization of Gases.**—It was mentioned in § 4 that under certain special conditions a gas may conduct at ordinary pressures, and in recent years the phenomenon of electric conduction in air at the ordinary atmospheric pressure has become familiar to medical men in connection with X-ray work and radio-active bodies, and also in connection with ultra-violet light. It is therefore important to consider this question with the object of obtaining clear ideas as to what is meant by the ionization of air or of other gases.

Manifestly the conditions are not strictly comparable to those occurring in an electrolyte, as, for example, in a solution of sodium chloride, for whereas the solution contains an abundance of negatively and of positively charged ions produced by the dissociation of the salt, a simple gas such as oxygen or nitrogen cannot become dissociated in the same manner. The ionization of a gas can be understood in the light of the theory of electrons,

for it can then be explained as the breaking up of the atoms of the gas into negatively-charged electrons and positively-charged remainders, and this is doubtless the explanation of what happens when a gas is rendered conducting by any one of the well-known methods, such as exposure to Roentgen rays, to radium rays, to ultra-violet light, or to heat, as, for instance, in a flame.

22. **Heating Effects of a Current.**—We saw in § 18 that a voltaic cell may be regarded as an apparatus by means of which the energy of the chemical action between the zinc and the exciting fluid or solvent can be in part converted into electrical energy, and the process may be regarded as a combustion in which the fuel is the zinc. If a piece of common zinc be simply dissolved in sulphuric acid in a test-tube the energy liberated serves only to warm the contents of the tube, but when the zinc is arranged in a voltaic cell some of the energy can be utilized in the form of an electrical current flowing through the circuit, and this current can be made to do work, or can be again converted into heat in any part of the external circuit of the cell. When an electrical current flows through a circuit, energy is absorbed by the resistance of the circuit, and is dissipated in the form of heat; or, in other words, a wire carrying the current becomes heated by the passage of the current through it. The amount of heat generated depends (1) upon the resistance of the wire, being proportional to the resistance, and (2) upon the magnitude of the current, being proportional to the square of the current. Accordingly, when it is wished to avoid the production of heat and the consequent loss of energy in a circuit, the conductors should be of low resistance; and conversely, when the current is to be used for the production of heat, as in the wire loop of a galvano-cautery instrument, or in the filament of an incandescent lamp, then the resistance of the part of the circuit which is to be heated must be made as high as may be necessary for the circumstances of the case, and a relatively bad conductor must be chosen for that portion.

23. **Resistance.** — A current is set up in a conductor by electromotive force—that is to say, there will be a current in a conductor if there be a difference of potential between its ends (§ 8). It is soon found in working with currents that with different conductors different currents are produced by the same electromotive force. There is, therefore, another factor that

determines the magnitude of the current besides the electromotive force, and this factor is called the *resistance* of the circuit.

The resistance of a conductor is the inverse of its conductivity, and the conducting qualities of a body may quite well be expressed in terms of its resistance ; thus the same idea is conveyed by saying that copper has a high conductivity, or that it has a low resistance. It is customary and convenient to speak of the resistances of bodies rather than of their conductivities.

The resistance of a conductor depends upon the material of which it is made, and upon its length and its thickness. Thus a thick wire has a lower resistance than a thin wire of the same length and material, and a short wire has a lower resistance than a long wire of the same thickness and material. This is expressed by saying that the resistance of a conductor is directly proportional to its length, and inversely so to its cross-section.

The electrical resistance of any material is a property peculiar to that material, just as its hardness or colour or density is. Most metals are good conductors, but they vary among themselves in their electrical conductivity. Silver is the best conductor of electricity, and copper comes near to it. Platinum has about six times the resistance of silver, and iron has a resistance slightly greater than that of platinum. As a general rule alloys have a higher resistance than the pure metals, German silver having about fourteen times the resistance of copper. Tables showing the relative conductivity of metals and other bodies are given in the textbooks.

Tables of resistance are also made with the *specific resistances* of the materials tabulated. The specific resistance of a material is defined as the resistance of 1 cubic centimetre of the substance considered.

If the specific resistance of a substance is known, the resistance of any wire or rod of that substance can be calculated.

In general the resistance of metals increases with temperature. Some alloys have been made in which variations of temperature have very little effect upon the resistance, and these are of special value for the construction of standard resistances. That of carbon, however, decreases considerably. The carbon filament of an incandescent lamp has nearly twice the resistance cold that it possesses when hot.

Just in the same way as the resistance of a metal or other

solid conductor is considered, so we may consider the resistance of a liquid or electrolyte.

The fact that electrolysis is taking place in an electrolyte does not prevent the consideration of its resistance in the same way as that of a non-electrolyte. Compared with metals the resistances of solutions are high; thus a salt solution may have a specific resistance upwards of a million times greater than that of copper.

As heat generally increases the resistance of metallic conductors, and decreases that of electrolytes, it is necessary to take account of temperature whenever measurements of resistance are to be made.

The measurement of resistance in electrolytes may be complicated by electrochemical relations existing between the electrolyte and the poles of the electrolytic cell, and electromotive forces set up in the cell itself may obscure or vitiate the results if they are not properly recognised and guarded against.

24 **Ohm's Law.**—The law showing the relation between electromotive force, resistance, and current was enunciated by Dr. G. S. Ohm, and is known as Ohm's law. It is as follows: *The strength of the current in any circuit or part of a circuit varies directly as the electromotive force in that circuit, and inversely as the resistance of the circuit.* This may be expressed in symbols thus:

$$C=\frac{E}{R},$$

where C stands for the current, E for the electromotive force, and R for the resistance. From this formula we obtain in addition $E=CR$, or $R=\frac{E}{C}$. Thus we can calculate either C, E, or R if the values of the other two symbols are known or can be measured.

25. **Practical Units.**—The units of electrical quantities are all ultimately defined in terms of the units of mass, length, and time, and as in all scientific calculations these are taken to be 1 gramme, 1 centimetre, and 1 second respectively, the system of units is known as the absolute or centimetre-gramme-second (C.G.S.) system. It is found, however, that for practical calculation and use these units are not of a convenient size—*e.g.*, the units of electromotive force and of resistance are inconveniently small, and that of current is inconveniently large. The

following system of units derived from these has therefore been adopted for practical use.

Electromotive Force.—The practical unit is called the *Volt.* It is a little less than the electromotive force of one Daniell's cell (see § 31).

Resistance.—The practical unit of resistance is called an *Ohm.* The Paris Congress of Electricians in 1884 defined a unit of resistance to be called a *legal Ohm.* It is represented by the resistance of a column of pure mercury at 0° C., of a uniform cross-section of 1 square millimetre, 106 centimetres long, and weighing 14·4521 grammes ; it is slightly less than the true ohm of 10^9 C.G.S. units.

Current.—The current which is given by an electromotive force of 1 volt acting through a resistance of 1 ohm is called 1 *Ampère.*

Quantity.—One ampère flowing for one second carries 1 *Coulomb* of electricity past any point in the circuit. Another unit of quantity much used by engineers is the quantity of electricity which would be carried by 1 ampère in an hour. This is called an *ampère-hour.* It is equal to 3,600 coulombs.

Capacity (see § 11).—That capacity which would require 1 coulomb to charge it to 1 volt is called 1 *Farad.*

These names commemorate the labours of Volta, G. S. Ohm, Ampère, Coulomb, and Michael Faraday.

Even these units are inconveniently great or small at times, so certain prefixes are used to the names to denote multiples or submultiples of these quantities. Thus, a *megohm* is one million ohms, a *microvolt* is one-millionth of a volt, a *microfarad* is one-millionth of a farad, a *milliampère* is one-thousandth of an ampère ; this last is the unit of current used in medicine.

The energy expended in a conductor may be calculated from the current in the conductor and the electromotive force acting upon it, and the figure obtained by multiplying the electromotive force (in volts) by the current (in ampères) gives the rate of the expenditure of energy in terms of a unit known as a *Watt.*

If E represents the electromotive force and C the current, then the watts, W, expended in the conductor are expressed by EC.

In any simple conductor the energy expended takes the form of heat. We are consequently able to calculate the rate at which heat is generated in the conductor, and if we know its

specific heat, and the rate at which it loses heat at its surface, we can calculate the temperature after the current has passed for any given time.

A watt is not a measure of work done, but of the rate of doing work. To obtain a measure of work done the time during which it goes on must be also considered. Thus one watt for one hour, or, shortly, one *watt-hour*, is a measure of work done.

By Ohm's law $E=RC$, and if in the equation $W=EC$, RC be substituted for E, we obtain the formula $W=C^2R$, for the rate of doing work, for losses in a conductor, or for the heating effects of a current traversing a conductor.

The Board of Trade unit in which the energy sold to consumers by the electric lighting companies is measured is 1,000 watt-hours, or one kilowatt hour, and costs from threepence to sixpence.

This amount of energy can be made up in various ways ; for example, taking the ordinary pressure of supply as 100 volts, ten ampères at that pressure for one hour, or one ampère for ten hours, alike represent the amount of energy of one unit. A carbon filament incandescent lamp of sixteen candle-power requires about sixty watts to keep it at a proper degree of brightness, and on a circuit of 100 volts it takes a current of 0·6 of an ampère. Five of these lamps would use 300 watts, and if kept going for five hours the amount of energy absorbed would be 1,500 watt-hours, or one Board of Trade unit and a half, costing ninepence, if the price of the unit were sixpence. The modern metallic filament lamps of sixteen candle-power require only twenty watts, and the consumption of energy in them is therefore about one-third of that of the old carbon filament lamps.

26. **Thermo-Electricity.**—In 1822 Seebeck discovered that a difference of potential could be produced by heating or cooling the point of junction of two dissimilar metals. If a rod of bismuth be soldered to one of antimony, and the free ends be connected by a wire, a current will flow through the circuit so formed if the junction of the bismuth and antimony be heated or cooled, and the current will continue to flow so long as the junction is maintained at a different temperature to the rest of the circuit. When the junction is heated the direction of flow is from bismuth to antimony through the heated part, but when it is cooled the current flows in the opposite direction. Other metals, and some alloys and minerals, show the same effects.

The electromotive forces set up are small, but by the combination of many couples thermo-electric batteries or thermopiles have been constructed for practical use. The opposite effect can also be observed. It was discovered by Peltier, and is usually known as the " Peltier Effect." It is that if a current be driven through a thermo-electric junction the junction is cooled or heated according to the direction of the current. Thus a current passed from bismuth to antimony cools the junction, and a current from antimony to bismuth heats it.

27. **Chemical Batteries.**—Numerous modifications of Volta's original cell have been proposed from time to time with the object of improving it, so as to obtain as high an electromotive force as possible, to diminish the internal resistance of the cell, and to secure constancy of action. For medical work the most important point of all is to find a cell which will remain for a long time in good order without attention, and in which no wasteful chemical action goes on when the battery is not in use. On this account the Leclanché cell (§ 34) or some modification of it has almost entirely displaced the other types for medical purposes.

The limit of electromotive force that can be obtained from a single cell is soon reached, since, as shown in § 17, it depends almost entirely on the electrolytic solution pressure of a metal or substance. Tables are found in electrical textbooks of metals and other conducting bodies arranged in order, the most " electropositive " at the head of the table, the most " electronegative " at the foot. An abbreviation of such a table is the following:

Electropositive.
Sodium.
Magnesium.
Zinc.
Iron.
Lead.
Copper.
Silver.
Mercury.
Platinum.
Carbon.
Lead peroxide.
Electronegative.

The similarity between this table and that given in § 17 is easily seen.

This order is given for the elements in the presence of dilute acid; with other exciting fluids the order may be slightly different by reason of the influence which may be exerted by osmotic pressure and electrolytic solution pressure under varying conditions.

It follows that the cell with the greatest electromotive force would be one the poles of which consisted of the two materials at the extreme ends of the table, and many of the improvements in batteries made with the object of increasing the electromotive force have been by substituting bodies further down the list for the copper plate of Volta's cell. Thus in Smee's cell we find a platinized silver plate, and in Groves' cell a platinum plate, while in Bunsen's carbon is used. The best of these cells when working properly have an electromotive force of something under 2 volts; that of a Bunsen's cell is from 1·8 to 1·9 volts.

As will be seen in the description of secondary batteries, a positive plate of peroxide of lead affords a means of getting a high electromotive force, and the combination of it with a zinc negative plate has been suggested under the name of the zinc-lithanode battery, and has an electromotive force of 2·5 volts per cell.

If several cells be coupled together in series—that is to say, with the negative pole of the first joined to the positive pole of the second, and so on—the electromotive force of the combination measured from the positive pole of the first to the negative of the last cell will be equal to the sum of the electromotive forces of the cells taken separately; thus, when high electromotive forces are required, the arrangement of a sufficient number of cells in series provides a means of obtaining it. If ten cells of an electromotive force of 1·5 volts apiece be arranged in series, the electromotive force of the whole battery will be 15 volts. In medical treatment, an electromotive force of 30 or 40 volts may be required, and a medical battery is, therefore, provided with a suitable number of cells connected together in series to give such a voltage.

28. **Internal Resistance of Cells.**—This is determined by the concentration of the fluid in the cell, by the distance between the plates, and by the area of the plates. The internal resistance is low if the plates be large and close together, and high if the plates be far apart or small. If the whole circuit of a cell be considered,

and divided into two parts, the external circuit in the wire, and the internal inside the cell itself, then a comparison of the resistances of the two parts will show what proportion of the total electrical energy of the battery is available for use in the external circuit, and what proportion is expended uselessly inside the cell itself; for example, in the case of a cell having an internal resistance of 3 ohms, and connected through an external resistance of 6 ohms, the energy expended in the outside circuit will be two-thirds, and that expended inside the cell will be one-third of the total under these circumstances. If the electromotive force of the cell be 1·5 volts, then one-third of the total fall or slope of potential (or 0·5 volt) will be used up in the cell, and the remaining two-thirds (or 1 volt) will represent the working electromotive force of the cell available for the outside circuit.

If the external resistance be 997 ohms, and the electromotive force and internal resistance be as before, then the electromotive force acting upon the external circuit will be very nearly the same as the full voltage of the cell; actually it will be in the ratio of 997 to 1,000, or 1·495 volts.

Thus one sees that in certain cases the internal resistance of a cell is an important factor in determining its value as a source of current, while in other cases it is insignificant. In working with the large resistances of the human body, the internal resistance of the cells composing the battery is an unimportant matter, as it forms only a small fraction of the total resistance of the circuit, and the waste or loss of electromotive force inside the cells is, therefore, a small fraction also.

In working with low external resistances, as for the heating of a galvano-cautery instrument, and to a less degree in the illumination of parts of the body by incandescent lamps, the internal resistance of the cells becomes important, and special forms of cell with low internal resistances are required for such work. Cells which have a low internal resistance are much more quickly run down if allowed to go on discharging through a circuit of low resistance than are those with a high internal resistance. Accumulators, with their very low resistances, need special care in this respect, for if treated in that way ("short circuited") they may discharge at a relatively enormous rate, and be not only run down, but also permanently injured thereby.

29. **Arrangement of Cells.**—The arrangement of cells in series has already been alluded to, and is represented in Fig. 4. Cells

may also be arranged in parallel (Fig. 5)—that is to say, two or more cells may have their positive poles connected together to form one pole of the battery, and their negative poles in like manner to form the negative pole. When cells are connected in series, the electromotive force of the battery is the sum of the electromotive forces of the cells composing it; the internal resistance of the battery is also the sum of the internal resistances of the cells. When similar cells are connected in parallel, the electromotive force of the combination is no more than the electromotive force of one of its components; but its internal re-

FIG. 4.—SIX CELLS ARRANGED IN SERIES.

sistance is diminished in proportion to the number of cells coupled together. With six cells in parallel the internal resistance is one-sixth of that of one cell. It is sometimes useful to couple up the cells which are at hand in the best manner for obtaining the desired result, as the following example will show:

Suppose the resistance of a cautery is 0·1 ohm, and the cells to hand are of 1·6 volts each and 0·5 ohm internal resistance, and suppose that the cautery requires 8 ampères to heat it. If ten cells are coupled up in series, we shall indeed get an electromotive force of 16 volts acting through a resistance of 5·1 ohms,

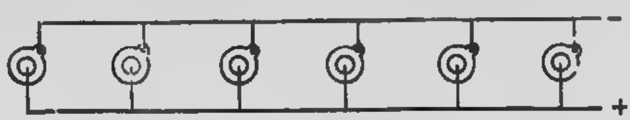


FIG. 5.—SIX CELLS ARRANGED IN PARALLEL.

and this will give a current of a little over 3·1 ampères; but if they are coupled in parallel, the battery resistance will be only 0·05 ohm, and the total resistance will be but 0·15 ohm in the whole circuit. True, the electromotive force will be only 1·6 volts, but by Ohm's law the current in this case will be 10·6 ampères. In the former case the cautery would not be heated, in the latter we should have enough current and to spare. Conversely it is of no use to arrange batteries in parallel when a current has to be passed through a high resistance, such as the human body, a resistance of at least 1,000 ohms, compared with

which the internal resistance of thirty or forty cells in series is small.

The coupling of cells in parallel has now lost its importance, owing to the introduction of accumulator cells, whose internal resistance is so small as to be a negligible quantity, at least in medical work.

30. **Polarization.**—In former days much ingenuity has been concentrated upon securing constancy of current and absence of polarization in batteries. This is easily seen to be an important matter, for nearly all voltaic cells undergo a fall of electromotive force when any large current is taken from them for any length of time. Polarization of a cell is mainly caused by alterations at the surfaces of the plates of the cell, and chiefly by the accumulation of hydrogen on the negative plate (§ 18), which reduces the available electromotive force of the cell by substituting hydrogen, whose solution pressure is relatively high for copper or carbon, in both of which it is low.

There are other causes which tend to produce a falling off in the current that a cell can give, particularly the saturation of the exciting fluid with zinc ions.

To prevent polarization it is necessary to take some measures that will oppose the formation of bubbles of hydrogen on the positive plate.

In Smee's battery the surface of the silver plate is roughened by being platinized—*i.e.*, covered with finely-divided platinum—the effect of which is that the bubbles of hydrogen are able to form and escape more easily. When a carbon plate is used, its rough surface plays the same part. A mechanical method of hindering polarization is to keep the exciting fluid well stirred by forcing air through it or otherwise. None of these methods, however, are so efficacious as the use of chemical means—that is to say, the use of some oxidizing agent in the cell whereby the hydrogen is consumed as fast as it appears on the positive plate. The simplest method of doing this is to add to the exciting liquid some oxidizing compound. This is the plan followed in the chromic acid cell (§ 33) invented by Poggendorf. Another liquid depolarizer that is used is strong nitric acid, but as this attacks zinc violently it is necessary to separate it from the zinc plate, where it would also be unnecessary, by the use of a semipermeable partition or porous pot, which keeps it in the neighbourhood of the positive plate, where its action is needed, and

the battery then becomes a two-fluid battery. In Fig. 6 the arrangement of a two-fluid battery is shown: V is the porous pot containing one liquid and one plate, the other liquid and the other plate standing outside it.

Solid depolarizers may also be used, the one best known being peroxide of manganese, which is used in the Leclanché cell. Oxide of copper has also been employed, while fused chloride of silver is the depolarizer in a battery known as the chloride of silver cell.

31. **Daniell's Battery.**—The oldest and most constant form of two-fluid battery is that known as Daniell's cell. So constant is this cell that it is sometimes used as a standard of electromotive force. Its electromotive force is 1·079 volts, but varies

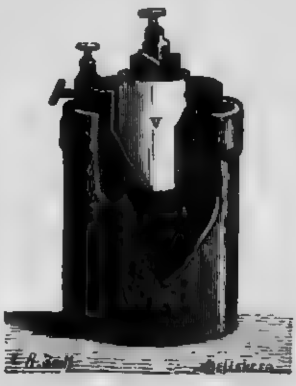


FIG. 6.—TWO-FLUID CELL.

slightly according to the nature and concentration of the solutions employed. A Daniell's cell consists of copper in contact with a solution of sulphate of copper kept saturated by crystals of copper sulphate placed on a shelf near the surface of the liquid, and separated by a porous partition is a zinc plate in contact with a solution of sulphate of zinc acidified with sulphuric acid. Frequently the copper is so shaped as to serve as the containing vessel. The porous partition, while it prevents the mixing of the two solutions, offers but little resistance to the electrolytic passage of the current. The reactions, then, are as follows: Zinc ions go into solution at the zinc plate, and copper ions go out of solution at the copper plate. Since this latter is already of copper, there is no tendency to polarization here at all, and so long as the copper sulphate solution is unexhausted there will

be no falling off in the electromotive force of the cell, unless from the accumulation of zinc ions opposing the solution of the zinc by osmotic pressure. Daniell's cells might be useful in medical practice for charging accumulators.

32. **Other Types of Cell.**—Grove's and Bunsen's batteries have for their depolarizer strong nitric acid. In the former the positive pole is a platinum plate, in the latter a plate or rod of hard gas carbon. In both batteries the negative plate is contained in a porous pot filled with strong nitric acid, and this is surrounded by the zinc plate contained in a vessel filled with dilute sulphuric acid. The fumes and the corrosiveness of nitric acid form the greatest objection to the use of this battery. It must be taken to pieces and cleaned every time it is used. If it can be set up in a draught cupboard or an outhouse it can be used for recharging accumulators, but the process is a disagreeable one.

The chloride of silver cell was invented in 1868 by Warren de la Rue and Hugo Müller, and modified and improved by Skrivanoff in 1883. The depolarizer is silver chloride fused round a rod or wire of silver, which forms the negative plate of the cell. The silver chloride tends to pass into solution after a time, and is reduced to metallic silver on the surface of the zinc. Local action then sets in, and the cell deteriorates.

The Lalande oxide of copper cell, as modified by Edison, consists of plates of zinc and copper : oxide of copper compressed upon the copper plate acts as a depolarizer : caustic soda solution is the exciting fluid (Fig. 7). The cells are very constant, and can furnish large currents. There is little or no local action. Their electromotive force is low, 0·8 of a volt, and they are not suitable for a portable battery, but might have a use in remote places for cautery work or for charging accumulators.

The sulphate of mercury cell consists of plates of zinc and carbon in a solution of sulphate of mercury.

Latimer Clark's standard cell is a form of sulphate of mercury cell which is used in laboratory experiments, but it requires the utmost delicacy in management, and is used solely as a standard for the comparison of electromotive forces ; its electromotive force is 1·434 volts at 15° C.

The primary cell has lost much of its interest from the introduction of electric light mains and of accumulators, so that almost the only chemical cells which concern the medical practitioner are the Leclanché dry cell, and to a less extent the chromic acid cell.

33. **The Chromic Acid Cell.**—This form of cell, sometimes called the "bichromate battery," is still in use where accumulators or electric light mains are not to be had, and where large currents are required occasionally. Its plates are of zinc and carbon, and the exciting liquid consists of a solution of potassium bichromate and sulphuric acid. Sodium bichromate has been recommended instead of the potassium salt, as the sodium salt contains, weight for weight, more chromic acid than the potassium salt. A suitable formula is the following: Potassium bichromate or sodium bichromate, 6½ ounces; water, 35 ounces; sulphuric acid, 6 ounces.

The chromic acid cell requires proper attention. If its action fails and the liquid is found to be green in colour, it must be

FIG. 7.—EDISON-LALANDE CELL.

renewed. The mixed materials for making fresh solution can be bought in a dry form in bottles. The battery requires to be taken to pieces occasionally, the carbon plates to be soaked in water and brushed with an old tooth-brush, and the zincs to be washed clean and amalgamated. For this they should be scraped smooth and wetted with dilute acid, and then some mercury should be well rubbed into them with a stick of wood wound round at the end with worsted. The surface, when properly amalgamated, looks as bright as silver, and should appear to be wetted by the mercury at every point.

The zincs of this battery must always be removed from the solution immediately after use, and, in fact, should be well cared for and frequently reamalgamated, if the battery is to give the

best effect. In medical work the chromic acid cells are now almost entirely abandoned, their place being taken by accumulators for heavy work, and by dry (Leclanché) cells in other cases.

34. **The Leclanché Cell.**—The cell most universally used for medical work is the Leclanché battery (Fig. 8), the exciting solution in which is a saturated solution of ammonium chloride (sal-ammoniac). The electrodes are zinc and carbon. The latter is surrounded by the depolarizer (manganese dioxide), which is able slowly to oxidize the hydrogen evolved by the action of the cell. In the usual forms of Leclanché cell the carbon pole is in a porous pot, and is packed round with fragments of carbon and of granular manganese dioxide. Another

FIG. 8.—LECLANCHÉ CELL.

form of cell has no porous pot, and the carbon has attached to it a conglomerate formed of manganese dioxide and carbon pressed into blocks. In another useful type the carbon and manganese dioxide are enclosed in a canvas sack.

When the circuit is not closed, there is no action between the solution and the zinc; but when the circuit is closed, the zinc is dissolved, while ammonia and hydrogen are evolved at the carbon pole. If only a small current is taken from these cells their action is fairly constant, but if much current is used the oxidizing action of the manganese dioxide is unable to keep pace with the evolution of hydrogen, and the cell becomes polarized, though it recovers again when left on open circuit. The advan-

tages of the battery are that it possesses great powers of recovery, does not waste when not in use, and will consequently supply current at intervals for months, or even years, without much attention. Its electromotive force is also fairly high—viz., 1·5 volts.

None of the cells in which dilute acid is used for the exciting liquid can be left to themselves in the same way as the Leclanché, for in all of them corrosion would gradually destroy the zinc if it were left in the acid.

Leclanché cells should receive a little attention about once in six months. The larger sizes in glass jars can be easily inspected, and the condition of the zincs and the level of the liquid ascertained.

If the zincs are blackened, they should be scraped and amalgamated, and the liquid can be renewed. The cells should not be filled to more than two-thirds of their capacity, because it is an advantage that the oxygen of the air may come into contact with parts of the carbon surfaces, and by being condensed there may assist in depolarizing. The proportion of 6 ounces of sal-ammoniac to a pint of water makes a solution of proper strength. The upper inch of the glass cells ought to be brushed over with vaseline to prevent "creeping" of the salts. This is the formation of crusts of the sal-ammoniac round the top and outer sides of the cells; it is harmful because it may lead to leakage and waste of current and to corrosion of connecting wires.

When hard crystals form in masses at the bottom of the cell and round the zincs, it is time to take down the battery and to set it up afresh. If there is reason to think that the cells are worn out, the porous pots may be recharged with manganese dioxide and broken carbon, which can be bought ready mixed, or, better still, they can be replaced by new ones.

The management of the small Leclanché cells used in portable batteries is much more difficult, because it is impossible to see their condition. One can do little beyond emptying out the liquid with a fine syringe, and putting in fresh sal-ammoniac solution in the same way from time to time. In the so-called dry cells this is dispensed with, and the latter are, therefore, more convenient, and they are also cheaper.

35. **Dry Cells.**—These are in many ways exceedingly convenient, and have come into general use for portable medical batteries. They are sealed cells of the Leclanché type, with a

pasty instead of a liquid exciting medium. They will work in any position, and do not require any special attention; but it must be remembered that the capacity for work of all sealed forms of cell is strictly limited by the original charge of chemicals, and cannot be restored, when run down, by the addition of fresh exciting fluid. In most of them the zinc plate is shaped like a canister, and forms the containing vessel of the cell; it is lined with a paste of exciting material, and inside this is the carbon and manganese dioxide. Cells of this type are now in general use, and exist in numerous makes and sizes.

The smallest size for portable medical batteries weighs about 8 ounces, and they will last for a year of daily use with proper care,

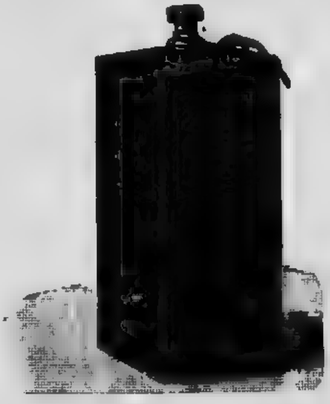


FIG. 9.—HELLESEN'S DRY CELL.

but after that time must be rejected. They cost eighteenpence apiece. Larger sizes are to be preferred for working medical coils.

36. **Accumulators, or Secondary Batteries.**—A so-called "secondary battery" has this property, that when it is run down and exhausted it may be renewed by driving an electric current into it, and thus setting up an electrolysis that brings the plates and the electrolyte back to their former state, while in the primary batteries it is necessary to renew these. There is no more actual storage of electricity in these batteries than in a primary battery. Either may be looked upon as a store of energy, and in both the energy stored is energy of chemical action.

An accumulator is a vessel containing two sets of lead plates, called the positive and negative plates, and a solution of sulphuric acid of the strength of 1 part of acid to 5 or 6 of water. Each set

of plates has a screw connection or terminal for the attachment of wires. In the smaller forms there are usually three plates, one positive and two negative, but there may be five, seven, eleven, or more plates in each cell. Each cell is complete in itself, but for convenience it is usual to arrange several cells side by side in one receptacle, and the cells are then connected together in series—that is to say, the positive of one cell to the negative of its next neighbour, and so on, leaving at one end of the series an unconnected positive terminal, and at the other an unconnected negative terminal. The accumulators in common use for medical purposes are made in teak-wood boxes, lead-lined, and having partitions to separate the cells.

Convenient small accumulators are also made for use on motor-cars, and these can easily be adapted for medical purposes by

FIG. 10.—ACCUMULATOR CELL, SHOWING ARRANGEMENT OF PLATES.

the exercise of a little ingenuity. These motor-car cells, or "ignition cells," are usually put together in pairs, and are enclosed in celluloid vessels, which makes it easy to inspect the plates at any time in order to ascertain their condition.

Both sets of plates are of lead, but as a result of their mode of preparation their surfaces are dissimilar, the positives being covered with a thick layer of dark chocolate-coloured peroxide of lead, while the negatives are grey from a surface of spongy lead. In many types of cell the plates or "grids" are full of small perforations, containing lead peroxide "paste" in one case, and spongy lead in the other. Positive and negative plates are kept apart by insulators of glass, or wood, or celluloid in the

form of rods or buttons between the plates. If by accidental movement of the plates a positive should come into contact with a negative, that cell rapidly becomes destroyed.

The chemistry of an accumulator is by no means simple, and it will suffice to state here that during discharge the lead peroxide becomes reduced to lead suboxide. The negative plates also change from metallic (spongy) lead to lead sulphate during discharge. The acid consequently becomes weaker, so that its specific gravity gives an indication of the state of charge in the cell.

The capacity of an accumulator cell varies with the size of its plates, and is expressed in ampère-hours, meaning that it can maintain a discharge current of so many ampères for so many hours. Thus a 10-ampère-hour cell can discharge at the rate of 1 ampère for ten hours, or of 2 ampères for five hours, and so on, and its charging must be in proportion. The charging and discharging current can be measured quite easily with an ampére-meter or ammeter, and the current in ampères multiplied by the time of flow gives the ampère-hours.

An accumulator is charged by passing a current into it in the direction from positive to negative through the acid, and when charged it is able to give out a current in the opposite direction, until the energy stored in it by the charge has been expended. The electromotive force of a charged cell is a little over 2 volts, and as the cells in a battery are connected in series, the joint electromotive force of a freshly-charged battery of four cells is 8 volts, or a little over. In practical working the electromotive force is reckoned as 2 volts per cell.

An accumulator may be charged and discharged for an almost indefinite number of times if charging and discharging follow each other at short intervals, but an accumulator tends to deteriorate if left for many days in a charged condition, and deteriorates much more rapidly if left long in a discharged condition.

Accumulators should not be charged or discharged at excessive rates. The proper rates are usually specified by the makers, but are not always adhered to by the users, and this is one reason for the short life of accumulators in careless hands. They should not be fully discharged, but as soon as their electromotive force falls below 2 volts per cell they should be recharged again as soon as possible.

In recharging there is not much danger of injuring them by

too prolonged a charge. When fully charged any surplus energy applied is expended mainly in the electrolysis of the acid, though the supports may be attacked if charging is much prolonged. A simple way of determining when a cell is fully charged is by auscultation. If a brisk effervescence can be heard the cell is fully charged. A slight effervescence may be heard before the charging is quite complete, and if the charging current is very small the effervescence is not particularly loud even when charging is complete; but a little practice will soon enable a judgment to be formed. There are other methods of determining when a cell is fully charged, but in the case of small medical cells these are more troublesome.

When a cell has just been charged, it will be found for a short time to have an electromotive force of nearly 2·5 volts, but the working voltage is 2 volts. When the cells are discharging, the electromotive force is maintained at this point till about 75 per cent. of the charge is expended; after that the electromotive force falls quickly.

It may be taken as a general rule that as soon as the electromotive force of a cell falls below 2 volts, or 1·8 at the lowest, that cell should at once be recharged. If it is not attended to, sulphate of lead is liable to encrust the surfaces of the plates, and this insoluble salt increases the internal resistance, and decreases the storage capacity of the cell until at last it may be ruined.

The internal resistance of a storage cell is almost infinitesimal when it is in good order, and may generally be neglected in calculations concerning them, at least in medical work. It is this low internal resistance which makes them so useful for cautery purposes, where large currents are needed.

The difficulties found in working with accumulators of the type having "pasted" plates has caused some makers to return to the original type of accumulator as invented by Planté, where no pastes of the oxides of lead are used.

The lithanode cell is a form of secondary cell which works well, and is made in several different sizes and in portable sets, some of which are admirably adapted for medical purposes. In the lithanode cells the positive plates consist of slabs of a very dense lead peroxide compound enclosed in a metallic framework, and they are free from some of the faults common to the "pasted" plates.

To charge an accumulator from a primary battery, the latter must have an electromotive force greater than that of the cells to be charged. For a two-celled accumulator, five Daniell cells, three chromic acid, or Bunsen, cells, or seven Edison-Lalande cells, are required. The charging cells should be large ; the process is as follows : The primary battery having been freshly charged, coupled in series (§ 29), and tested to see that it is in good order, it must be attached to the accumulator, positive pole to positive pole, and negative to negative. Current will then pass to the accumulator from the battery so long as its electromotive force keeps up above that of the secondary cells. The current will slowly diminish as the primary cells run down. When the electromotive forces of the primary and secondary cells are in equilibrium no current passes in either direction, and the charging consequently comes to a standstill.

The operation should accordingly be watched, and stopped before the charging current has fallen too low. An ampère-meter or ammeter (§ 58) will show the magnitude and direction of the current which is passing. By noting the magnitude of current at intervals during the charging process, an idea is obtained of the amount of the charge. For example, suppose the duration of the charge be six hours, and the current during the first hour be 3 ampères, during the second and third hours 2 ampères, during the fourth 1 ampère, and during the fifth and sixth ½ ampère, then the charge will be in ampères for each hour, 3, 2, 2, 1, ½, ½, or 9 ampère-hours. The charging of accumulators from primary batteries is now rarely practised, as there are few places where electricity is used in which current from a dynamo is not available. For charging from a dynamo or the electric light mains, see Chapter IV., § 94.

The Edison accumulator is a cell having for its active materials nickel peroxide and iron. The electrolyte is a solution of caustic potash. Both plates are of nickel-plated steel, with numerous recesses or pockets to contain the active materials.

During the discharge of the cell the nickel peroxide changes to a lower oxide at the positive plate, and at the negative the metallic iron becomes oxidized. During charging the cycle is reversed.

The plates of the cell appear to act merely as conducting supports, and take no part in the chemical reactions.

The cells are said to behave well under trying conditions.

Irregular charging and discharging do not affect them so unfavourably as is the case with lead accumulators. They are not yet in practical use. The working electromotive force of the cell is 1·3 volts.

37. **Magnetism—the Magnetic Field.**—When a magnet is suspended freely at the surface of the earth, it is found that it swings so as to set itself with one pole pointing towards the north (or at least approximately so) and the other towards the south. The poles are spoken of as the *north-seeking* and *south-seeking* poles respectively, and these names are abbreviated into north and south (N. and S.) for convenience.

The region of space about any magnet, and throughout which we consider its action, is called its *field*, and lines of magnetic induction or lines of force round a magnet can be mapped out. These will then all leave the iron at points or surfaces indued

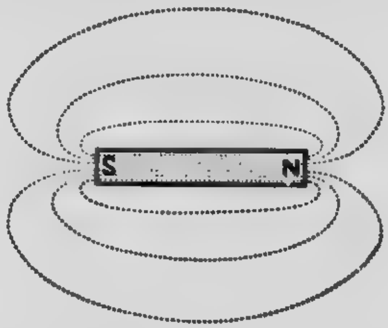


FIG. 11.—LINES OF FORCE OF A BAR MAGNET.

with N. magnetism, and will return to it at points or surfaces indued with S. magnetism, and the intensity of a magnetic field at any point will be given by the number of lines of force which cross per unit of surface at right angles to them at that point.

It is easy to map the field of force round any magnet, since every magnet tends to set itself parallel to the lines of force at the point where it is. If, then, the magnet whose field is to be mapped be laid down on a sheet of white paper, and a small compass needle be moved about in its vicinity, the direction of the needle at any point will give the direction of the lines of force at that point, and these can be plotted on the paper. And soft iron filings in a magnetic field set themselves along the lines of force, mapping them out to the eye in a very beautiful manner.

If a sheet of paper be laid down over a bar magnet, and iron

filings be sifted over the paper, and the paper be gently tapped, they will arrange themselves into a figure composed of curved lines which emerge from one pole, and pass round to converge at the other (see Fig. 11).

38. **Oersted's Experiment.**—Let a small magnet, say a compass needle, be suspended freely at rest; it will point north and south. Now over it let there be carried a wire joining the two terminals of a voltaic cell or battery in such a way that its course from copper to zinc along the wire shall be from south to north—*i.e.*, so that the current (the positive direction of flow) is from south to north—then the north-seeking end of the magnet will be deflected towards the west. This observation is due to Oersted of Copenhagen, and it was formulated by Ampère into a law for telling the direction of flow in a circuit thus: Imagine a man swimming with the current in the wire—*i.e.*, from copper to zinc—and facing the needle, the north-seeking end of the magnet will always be deflected towards his left hand, whatever the position of the wire with regard to the magnetic needle.

From Oersted's experiment we can draw the deduction, viz., that there must be a magnetic field of force about every wire that is carrying a current, and since, when we are facing the magnet and swimming with the current, the N. pole is always deflected to the left whatever the position of the magnet with regard to the wire, it follows that the lines of force must pass round the wire in circles, and it is easily shown that they do so by scattering iron filings on a card through a hole in which a vertical wire carrying a moderately strong current is passed. When the card is tapped the filings instantly arrange themselves so as to map out the lines of force as circles round the wire; also, if we look along the wire from copper to zinc—*i.e.*, with the current—the direction of the lines, the direction in which a N. pole will move, is that of the hands of a clock. If a wire be bent into the arc of a circle, when a current passes through this arc there will be a field of force at the centre of the circle, due to the current at all points of the arc. If the arc were in the plane of the paper, and the current ran clock-wise in it, the direction of the lines of force would be vertically down from the paper.

It was believed by Ampère that a magnet was the seat of molecular electric currents, all revolving in a similar direction, and in the terms of the electron theory a magnet is a piece of

iron or steel whose electrons are revolving in similar orbits, whereas these orbits are arranged irregularly when the metal is not magnetic. On the electron theory it is assumed that the atoms of all matter contain one or more electrons which are in continual revolution round the centre, in orbits. They circulate in all sorts of planes, and their orbits face every way. For iron, when brought into a field of magnetic force, the orbits are drawn round into parallel positions, and when the field of force is withdrawn, some magnetism remains, because some of the orbits continue in their new position. With soft iron the permanent magnetism thus produced is very feebly preserved, and a mechanical shock is sufficient to cause most of it to disappear, but with steel the magnetism so produced is much more permanent.

39. **The Electromagnet.**—To illustrate the magnetic properties of a wire carrying a current many devices have been used from time to time as lecture experiments, and some have had important practical applications, as, for instance, the electromagnet and the galvanometer. Soon after the discovery by Oersted of the effect of a current upon a magnetic needle it was found that a wire coiled into a spiral or helix behaved as a magnet when a current traversed it, and the effect became very much more conspicuous if the helix were wound upon an iron rod or core. The explanation of the effect of the iron core is as follows: Iron conveys magnetic lines more readily than air does, and therefore a given magnetizing current will set up a larger number of magnetic lines when the path for these is either partly or wholly in iron than when it is wholly in air.

By winding a coil of insulated copper wire around horseshoe-shaped pieces of soft iron, Sturgeon constructed magnets of great power, and gave them the name of electromagnets. Since his time electromagnets have had many useful applications, and as the field magnets of dynamo machines and motors they now play a most important part in the industrial applications of electricity.

Whenever a magnetic field is set up by the passage of a current, the growth or formation of the magnetic field is accompanied by an absorption of energy. This energy is not lost, but is stored in the magnetic circuit, to be released again during the collapse or decay of the magnetic field which takes place when the current in the circuit is cut off. A mechanical analogy to this is seen in the storage of energy in a compressed elastic body such as a spring.

The energy stored in a spring pistol is recovered suddenly, and often with striking effect, when the pistol is discharged, while in the case of the movement of the springs of a vehicle travelling along a rough road we have an instance of energy stored and liberated in a rhythmic or oscillatory manner.

When a circuit is so arranged as to make the most of these magnetic effects very marked, phenomena may be noted, and many electromagnetic mechanisms depend for their action upon the sudden release of stored energy which occurs during the rapid decay of a strong magnetic field.

40. **Galvanometers.**—Oersted's discovery at once provided a means of making an instrument for measuring the current in a circuit. Such an instrument is called a galvanometer; or, if it is used merely to indicate the presence of a current, it may be called a galvanoscope.

In its simplest form the galvanometer consists of a number of turns of wire disposed in a vertical plane, with a small magnetic needle suspended or supported freely at the centre. The needle, being free to move, sets itself parallel to the magnetic field that happens to exist at the place where the galvanometer is to be used, and the coils of the instrument are then set parallel to the needle, and therefore to the magnetic field at the place. Hence the field due to a current circulating in the coils will be at right angles to the position of rest of the needle, and will tend to deflect it.

By multiplying the number of turns of wire in the galvanometer coils the action of the current on the neeedle becomes increased in proportion, each turn exercising its own effect. On this account the name of "multiplier" was once given to the galvanometer. But it must not be forgotten that, if the number of windings be largely increased, resistance (§ 23) is thus introduced, which may have the effect of diminishing the current flowing through the coils. It is therefore necessary to wind galvanometer coils so as to suit the special purposes for which they are intended to be used. The galvanometers used for medical purposes are generally wound with numerous turns, for though the resistance thus added to the circuit may be considerable, the resistance of the body itself is very high, and the effect of the galvanometer resistance in diminishing the current is unimportant as compared with the advantage gained by the multiplying effect of the turns of wire. Thus the small currents

used in medical treatment are enabled to produce large deflections of the galvanometer needle.

It must not be forgotten that the deflection of the needle of a galvanometer is not a direct measure of the current circulating in it. Galvanometers must be constructed to suit the special purposes for which they are intended, and some instruments will give considerable deflections with minute currents, while others require currents of huge magnitude to produce even a slight movement of the needle. On this account it is necessary, before comparing the deflections of one galvanometer with another, to be able to express their deflections in current, and galvanometers may be graduated by comparing them with standard instruments. When buying an instrument it is customary to specify the magnitudes of current which it is proposed to measure with the galvanometer required; the instrument-maker is then able to provide a suitable instrument, which has been already graduated to read directly into current.

41. **Measuring Instruments.**—A galvanometer graduated to give readings in ampères is commonly known as an ampèremeter or ammeter. The currents used for medical applications are usually measured in milliampères (§ 25), and the galvanometers used are called milliampèremeters. Galvanometers can be graduated to give readings in volts, and are then called voltmeters. They are useful when it is wished to measure the electromotive force existing between two conductors at different potentials, as, for example, between the poles of a voltaic cell or battery.

Many devices depending upon the magnetic properties of a wire carrying a current have been adapted for measuring purposes. Similarly, the heating effects of a current, the electrolytic or chemical effects, and the effects of electrostatic attraction (§ 2), have been used in the construction of measuring instruments.

42. **Measurement of Resistance.**—A galvanometer may be used for calculating the resistance of a circuit or of a part of a circuit. Suppose a Daniell's cell of electromotive force 1·1 volts be connected up through a galvanometer, and the reading of the latter be 0·05 of an ampère, then the resistance of the circuit will be by Ohm's law—

$$R=\frac{E}{C}=\frac{1\cdot 1}{0\cdot 05}=22 \text{ ohms.}$$

The resistance of 22 ohms will be made up of the resistance of the cell, of the conducting wires, and of the galvanometer coils. Now, suppose a coil of wire, whose resistance is to be measured, be included in the circuit as in the figure, and the reading of the

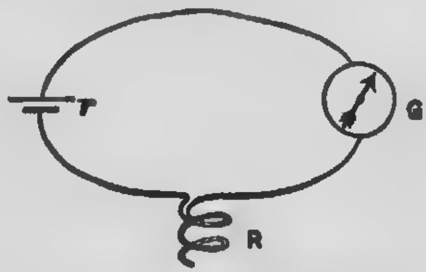


FIG. 12.—MEASUREMENT OF RESISTANCE.
r, Battery; G, galvanometer; R, wire resistance.

galvanometer be taken again. Suppose it to be 0·02 of an ampère, then by the same calculation, $R = \frac{1\cdot1}{0\cdot02} = 55$ ohms, the resistance of the circuit has been increased by 33 ohms, which is the resistance of the coil of wire which was to be measured.

43. **Resistance Coils.**—The method of calculating resistances described in the preceding paragraph is often useful for rough determinations in medical work. In using it we have to rely upon the correctness of the galvanometer, and upon our knowledge of the electromotive force of the battery used. When exact measurements are needed another method is employed by which

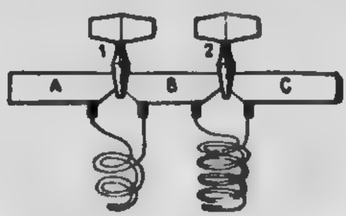


FIG. 13.—P . I OF RESISTANCE COILS.

these elements of uncertainty are avoided, and the resistance is measured by comparing it with that of standard "resistance coils." Permanent standard resistances are made from lengths of wire specially wound into coils, and sets of these coils of suitable resistances are sold by instrument-makers in a convenient form. The wires are made of German silver or of some

other alloy whose resistance does not change very much with changes of temperature. The coils are enclosed in a box for protection, and are connected to consecutive sections of a heavy brass conductor upon the outside of the box, as shown in Figs. 13 and 14. The plugs are used to cut out any of the coils which are not to be included in the circuit. When a plug is inserted the current flows across the plug to the next section, and there is practically no resistance at that point. When a plug is withdrawn, the current must pass through the coil. With a set of coils arranged in the following order: 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, any resistance from 1 to 2,100 ohms can be put into circuit as any of the coils can be thrown in or out of circuit by removing or replacing plugs on the top of the resistance-box. Such a resistance-box can be used to measure resistances by what is called the "substitution method." A

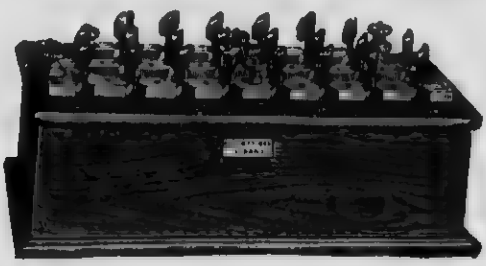


FIG. 14.—RESISTANCE-BOX.

battery, a galvanometer, and the unknown resistance are connected together in circuit, and the deflection of the galvanometer is noted. A resistance-box is then substituted for the unknown resistance, and the box is unplugged till the deflection has the same value as the first, when the resistance unplugged gives the value required.

44. **Wheatstone's Bridge.**—The method generally used for measuring resistances is called Wheatstone's bridge method, and consists of an arrangement of conductors as shown diagrammatically in Fig. 15, in which P is a battery having its circuit divided along two channels at B, and reunited at D, so that part of the current flows through A and part through C. When the current is flowing thus there is a gradual fall of potential along both wires, so that for every point along one there is a point along the other which is at the same potential, and therefore a galvanometer attached to these corresponding points would

show no deflection, as there would be no current. If A and C are these points, and a b c x are the resistances of the various branches as drawn, when there is no current indicated by the galvanometer we have the relation $a : b = c : x$, and if a, b, and c are known, the fourth, x, can be calculated from this proportion. The resistance to be tested is joined in between A and D as shown at x in the diagram, and the resistance-box is joined in between C and D. Then, as the simplest case, if the resistances at a and b are equal, the resistances at c can be changed by taking out or putting in the plugs of the box until a balance is obtained, and there is no current through the galvanometer. The sum of the resistances in the arm c is then equal to the resistance of the conductor to be measured. The Wheatstone's bridge method has been much studied and developed, and for details

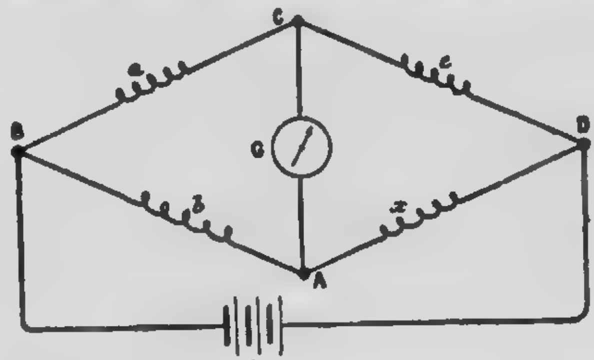


FIG. 15.—WHEATSTONE'S BRIDGE.

as to the use of the instrument, the various forms it takes, the precautions necessary in working with it, and for a description of the resistance coils, and the way they are wound and adapted, reference must be made to Kempe's "Handbook of Electrical Testing," or other modern textbook of electricity.

45. **Electromagnetic Induction.**—When two distinct circuits are near to each other, currents in one will "induce" currents or, more correctly, electromotive forces in the other.

The induced currents are of momentary duration, and appear only when the inducing current is made to vary, as, for example, when it is turned on or turned off. The current induced at the starting of the inducing current is opposite in direction to the inducing current, and the current induced at the break of the inducing current has the same direction as the inducing current.

This has been formulated by saying that the induced current is such that the field it would set up tends to neutralise the change in field that is causing it (Lenz's law). These induced currents were discovered by Faraday, and on that account the induced currents employed in medicine are still known as "Faradic currents" among medical practitioners.

In § 38 it was stated that there is a magnetic field of force about every wire carrying a current, and the effects just referred to depend upon the field of force surrounding the wire of the inducing circuit, and generally it may be said that every change of the magnetic condition of the space round a conducting circuit produces an induced E.M.F. or current in the circuit. Thus, the increase or decrease of a current in the inducing circuit, or the approach or withdrawal of the inducing circuit will change the magnetic conditions round the other circuit, which may be termed the "secondary" circuit, and will set up a current in it. Also, for the same reason, the approach or withdrawal of a magnetic pole will set up a current in a circuit during the periods of approach or withdrawal, and since the induced current depends upon the variation of the magnetic field in which the circuit is placed, it matters nothing whether the field is caused to vary by moving the magnet or the coil, or by making and unmaking a magnet by any means, or by varying a current in a neighbouring circuit.

The production of electric currents by electromagnetic induction is of enormous practical importance. The commercial developments of electricity rest upon the dynamo machine, which is an apparatus for the generation of electricity by the induction effects of magnetic fields upon coils of wire. The importance of the dynamo machine lies in the fact that it affords a means for the direct conversion of mechanical power into electrical power. It does this simply and efficiently so that the primary battery is no longer used as a source of electrical energy, except for minor and special purposes.

46. **Induced Electromotive Force.** — It was stated at the commencement of § 45 that "currents in one circuit will induce currents or, more correctly, electromotive forces" in another. The meaning of the correction is that, although the induction of currents implies the induction of electromotive forces, yet electromotive forces may exist without being able to give rise to currents. An electromotive force can only give rise to a current when

there is a conducting path for the current. In the case of a circuit acting inductively upon a conductor near it, the latter would be the seat of a current if it formed part of a closed conducting circuit; but if it did not do so it would be the seat of an electromotive force only, as its circumstances would be against the production of a current in it.

In order to arrive at the magnitude of induced currents we must consider that by Ohm's law (§ 24) this depends upon two quantities, the electromotive force and the resistance of the wire. This latter is constant, since it depends only on the wire; the electromotive force alone varies. Its direction has been already considered; its magnitude is determined by the following law: The total induced electromotive force in any closed circuit is proportional to the rate of change of the number of magnetic lines of force through the space enclosed by the circuit. But, the number of lines of force, or, in other words, the strength of the magnetic field produced by a current in a circuit, is proportional to the current in that circuit. Hence the law may run, "the induced electromotive force in any closed secondary circuit is proportional to the *rate of change* of current in the primary circuit."

47. **Self-induction.**—When a current is sent through a circuit, the magnetic field which is set up round the conductor reacts upon the conductor itself, just as we have seen it do upon a neighbouring circuit, and thus at the moment of completing a circuit the rise of current in it to its proper value is retarded by an induced electromotive force of opposite sign in the wire itself, while when the circuit is broken there is a momentary reinforcement of the current by an induced electromotive force of the same sign as that existing in the wire. This action of an increasing or decreasing current upon its own circuit is spoken of as an action of self-induction, and the reinforcement of the current at the break produced in this way can be amplified and made use of, as will be seen later in the account of induction coils.

The effect which self-induction has of retarding the growth of a current in a wire is not of great importance in the case of steady currents, because the effect is a transient one. In dealing with currents which are in a state of continual variation it is soon found that the matter may be one of very great importance. In the distribution of electrical energy by alternating currents,

which is a common form of electric supply, a consideration of the self-induction of the circuits is absolutely necessary if serious errors are to be avoided.

Conductors supplied with alternating current, especially when they are wound in the form of coils so as to set up strong magnetic fields, are found to have an apparent resistance which is very much greater than they have when tested by steady currents, and the introduction of an iron core into a coil of wire which is carrying an alternating current can easily be shown to produce a still further increase in its apparent resistance. From this it is clear that Ohm's law (§ 24), which specifies that the magnitude of a current in a circuit is determined by two factors only—viz., the electromotive force and the resistance—needs to be modified for the case of varying currents by the introduction into the calculation of a new factor: namely, the self-induction of the circuit. It is the opposing electromotive force, or *back E.M.F.* of self-induction, which increases the apparent resistance.

Sometimes it is convenient to use the expression "ohmic resistance" to signify the resistance of a circuit as measured for steady currents, and to distinguish it from the "virtual resistance" of the same circuit when varying currents are being considered. The word "impedance" is generally used for virtual resistance.

It is very necessary for medical men to have some knowledge of the phenomena of electromagnetic induction, and of the behaviour of circuits carrying varying currents. Without an acquaintance with this part of the subject it is impossible to understand the induction coil, or the construction and management of the various forms of medical apparatus in which alternate currents are used. "High-frequency" phenomena, too, can only be comprehended by those who have given attention to the effects of self-induction and mutual induction. The preceding paragraphs may serve to indicate the importance of the matter, but for a proper elucidation of the laws of varying currents and of electromagnetic effects in general the reader must consult a modern textbook of electricity.

48. **The Induction Coil.**—One of the most interesting of the early observations in connection with electromagnetic induction was that shocks and bright sparks could be produced from a single voltaic cell if the circuit contained spiral coils of wire. From the last paragraph we learn that these effects depend upon the self-

induction of the circuit, and very shortly after the publication of the researches of Faraday and of Henry in 1831 and 1832 the subject was taken up by others, and coils were made by Page, Sturgeon, Callan, and others, which were the prototypes of the modern induction coil.

The peculiar physiological effect or shock which these induction coils produced soon led to their application to medical treatment, and in 1837 a machine contrived for this purpose by a Mr. Clark was figured in Sturgeon's "Annals of Electricity."* Others quickly followed, and the drawings of the period commonly represent these coils as fitted with handles for patients to grasp, showing the general idea of the mode of employing them in therapeutics. By the introduction of the separate "secondary" coil, and of the automatic contact-breaker, the induction coil acquired its modern form.

Since then the medical induction coil has undergone many modifications at the hands of ingenious instrument-makers, but few of these modifications have been of much value, because the principles determining the physiological action of the coils have received but scant attention. (See Chapter II. (§ 59) for a detailed account of medical coils.)

It is convenient to consider the phenomena of the induction coil as depending on the variations in the magnetic field of force (§ 38) of a coil of wire in which a current is continually being made and broken. The magnetic field set up in and around the coil at the moment of closing the battery current reacts upon the wire and produces in it a wave of opposing electromotive force, which retards the growth of the current so that it does not instantaneously reach its full strength, and the collapse of the magnetic field at the moment of breaking the current also sets up a wave of electromotive force in the wire, which strengthens the battery current, and shows itself by a bright spark at the place where the circuit is broken.

In its simplest form an induction coil consists of a single coil of insulated wire wound round a reel or bobbin with an iron core, and provided with an arrangement, usually a vibrating spring, for automatically closing and opening the circuit. It is connected to a voltaic battery whose current passes through the interrupter. Thus the current is periodically established and

* For an interesting account of the early history of the induction coil, see Fleming, "The Alternate-Current Transformer."

interrupted in the windings of the coil, and the magnetic field of the apparatus is caused to vary with every make and break of contact, and the current induced in the wire coil at break can be led off by properly-arranged conductors, and is the so-called "primary current" of a medical coil, being distinct from the battery current. The primary current is a series of impulses or waves all passing in the same direction, and corresponding in time and frequency to the interruptions of the battery current; each wave is due to a sudden rise and fall of electromotive force in the wire, the whole time of each wave being a very small fraction of a second, and varying considerably in different coils.

The secondary current of an induction coil, as its name suggests, is derived from a second entirely independent coil wound upon the same bobbin as the primary coil. Being in the same magnetic field as the primary coil, it is acted upon in the same way, but the effects produced in it are not quite the same. In the secondary coil there is an induced electromotive force corresponding to the rise of magnetism, and an opposite electromotive force corresponding to its fall. Both of these can give rise to currents through an external circuit, and because they are in opposite directions the currents from the secondary coil are said to be alternating. They are not exactly alike in all respects although the total flux of electricity is the same in each; for the electromotive force set up at the "make" of the battery current is lower, and the duration of the wave is longer than at the break, because the rise of the magnetizing current in the primary or inducing coil is more gradual than its fall.

The electromotive forces developed by induction in the primary and secondary coils vary very much in different instruments. In both coils the electromotive forces reach maxima which are higher than that of the battery which supplies energy to the apparatus.

Fig. 16 is a plan of the arrangement of the wires in an induction coil, and Fig. 17 shows an actual coil. The lettering is the same in both of the figures. One pole of the battery is connected to the coil at A. The current then passes by the adjusting-screw B, the vibrator H, and the support K, to a magnet D, which actuates the contact-breaker. After traversing this the circuit gives off a branch to the binding-screw P, and is continued to the primary coil E, E, the return wire from which

again gives off a branch to the second binding-screw at P, and is then continued to the other pole of the battery. The two binding-screws at P are thus in connection with the two ends of the primary coil, and by means of electrodes attached to

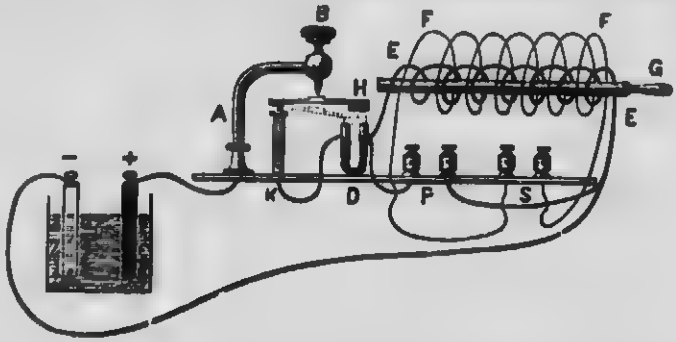


FIG. 16.—ARRANGEMENT OF WIRES IN AN INDUCTION COIL.

them the patient may be treated with the primary current of this coil. The secondary coil F is wound on a separate hollow bobbin, and has its terminals at S. This bobbin is made to

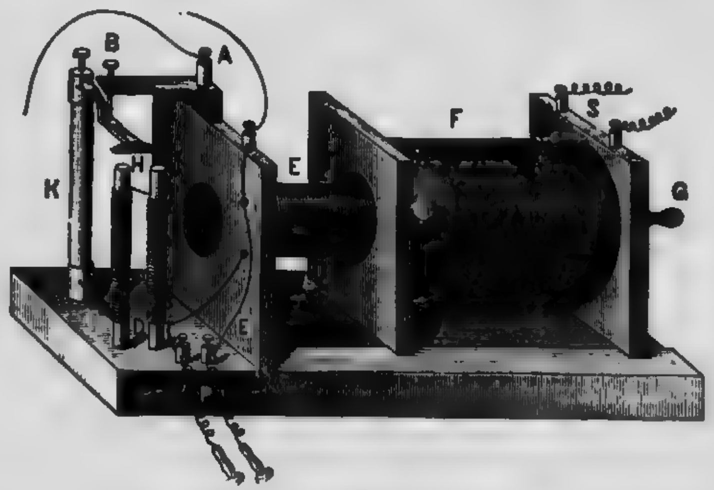


FIG. 17.—INDUCTION COIL.

slide like a sledge on guides, so that it can be made to approach or recede from the primary coil. At G a handle is seen attached to the iron core which can slide in and out of the primary coil, and so further modify the electromotive forces induced in the primary and secondary coils by varying the strength of their magnetic field.

The mode of action of the automatic vibrator or contact-breaker is clearly shown in the figures. The electromagnet D, by attracting the iron armature H, draws down the spring and breaks the circuit at the point of the screw B, whereupon the attraction of the electromagnet ceases and the spring is released, and flying up, re-establishes the circuit; the action is then repeated, and the spring is kept in constant movement. By turning the screw B the pressure upon the spring and its rate of vibration can be modified. Instead of the separate electromagnet, it is easy to utilize the magnetism of the iron core of the coil for working the contact-breaker, and this is done in those patterns of medical coil which have a fixed core; but in that case some mode of regulation other than that of a sliding core is required.

In order that the coil may be used for medical purposes there must be some method of regulating its strength (§ 59).

49. **The Dynamo Machine.**—Commercial applications of electricity would not be possible without the dynamo, because the primary battery, convenient as it is for some purposes, is altogether unequal to the work of producing electrical currents on a sufficiently large scale. Even in medical work there are now many applications of electricity which require currents of such magnitude that a dynamo or electric light mains are absolutely necessary for them.

In a dynamo there is a fixed magnetic part or "field-magnet," and a moving system of conductors or "armature," which rotates in the magnetic field between the poles of the field-magnet.

In the early days of dynamo electric machines the field-magnet consisted of one or more permanent steel magnets. Instruments of this kind still survive, and under the name of "magneto machines" have had a certain vogue for medical purposes. Otherwise electromagnets have now completely superseded permanent magnets for dynamos, and though the shapes seem to vary in different types of machines, all are essentially horseshoe magnets or groups of these.

The field-magnet of a dynamo is an electromagnet magnetized or "excited" by the passage of a current through the coils of wire wound upon it, the current for the purpose being usually taken from the armature of the machine. The slight permanent magnetism which exists in all field-magnet cores is sufficient to start small currents in the armature when it is rotated.

These currents traverse the windings on the field-magnet, and strengthen it so that it reacts more strongly on the armature, until by the continuance of this mutual reaction between the armature and the field-magnet the latter becomes fully

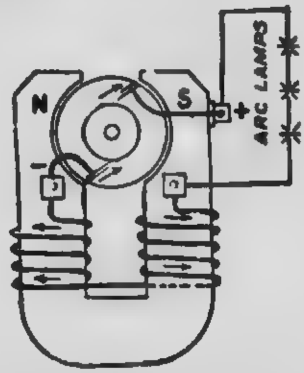


FIG. 18.—SERIES-WOUND DYNAMO, WITH THREE LAMPS, ALSO IN SERIES, IN EXTERNAL CIRCUIT.

magnetized, and the dynamo becomes a self-exciting machine. The armature is mounted on a shaft, and if it is designed to give direct current—that is to say, a current running in one direction, and not alternating, the shaft is fitted with a commutator.

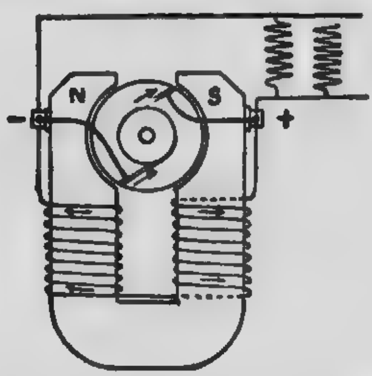


FIG. 19.—SHUNT-WOUND DYNAMO, WITH TWO RESISTANCES, ALSO IN SHUNT, IN OUTER CIRCUIT

This consists of a circle of copper or brass segments insulated from the shaft and from each other ; the ends of the coils of wire which form the armature are connected to a pair of these commutator segments, and when the armature is in rotation the seg-

ments pass in turn under the ends of two collecting-brushes of metal which make contact with them.

The commutator is a necessary part of a direct current dynamo, for it serves to rectify the alternate currents generated in the coils during their rotation, and delivers them to the field-magnet coils and to the outside circuit as a continuous current in one direction. For alternating-current machines the commutator is replaced by two insulated metal rings on the shaft, and the ends of the wire are attached to them. The collecting-brushes touch these, and collect an alternating current. The field-magnet of an alternator must either be a permanent magnet, or else it must be excited from a separate source of direct current.

When the whole of the current from the collecting-brushes passes first through the field-magnet coils, and then through the outer circuit, the dynamo is said to be "series-wound," the two portions of the circuit being in series, whereas a "shunt-wound" dynamo has the field-magnet coils in parallel or in "shunt" with the outer circuit (Figs. 18 and 19). Each of these arrangements presents advantages for certain purposes.

50. **Power for Dynamo-driving.**—With the magnitudes of current and at the pressures needed for much of the electro-therapeutic work of to-day, chemical batteries are insufficient as the source of current. In the absence of a public lighting supply a dynamo is almost a necessity, for the transportation of accumulators to and from a charging station is expensive and troublesome. On the other hand, it is rather an undertaking for a medical man to set up a private dynamo for charging the accumulators, for one needs not only the dynamo, but also the power to drive it.

Manual power, windmills, water-motors, hot-air motors, and gas and oil engines, have all been applied to the driving of dynamos. In any particular case the local conditions will help to decide which is likely to be the most convenient source of power. In charging an accumulator from a dynamo the electromotive force of the charging source must be maintained steadily above that of the cells to be charged, for if this is not done the cells will discharge back through the dynamo, with a result quite opposite to that desired. On this account manual power is too unsteady for serious purposes. An apparatus for dynamo-driving has been contrived by adapting a bicycle, and so making

use of pedal power, and it is interesting to note that electricity for charging accumulators for Roentgen-ray work in the Soudan campaign was generated by means of an apparatus of this kind, a tandem bicycle being so converted as to drive the dynamo by means of a belt from the hind wheel. (See the illustrated paper by Surgeon-Major Battersby in the *Archives of the Roentgen Ray* for February, 1899.)

In some places a small windmill might be used for charging purposes, and where there is a cheap water-supply a water-motor gives little trouble and would be a good contrivance.

Many makers now list small gas-engines of one-quarter horse-power, which can be used to drive a dynamo for charging storage cells. These would probably answer for charging purposes quite well in the hands of anyone who was willing to take some trouble to understand them thoroughly. Several firms now supply gas engines of small power together with dynamos. In the size of one-half horse-power, the Gardner engines,* for gas and oil, cost £15 and £25 respectively, and can be specially provided with dynamo, pulleys, belts, etc., complete, for about £10 more. With one of these sets the charging of storage cells can be effectively dealt with.

When charging an accumulator from a dynamo, the possibility of an unexpected stoppage of the machine must be borne in mind. To meet this chance automatic switches have been contrived which at once cut off the cells from the dynamo circuit if anything goes wrong. This is necessary to prevent the charge already accumulated in the storage cells from running down through the dynamo circuit, to the probable damage both of dynamo and cells. A shunt-wound dynamo must be used for the purpose of accumulator charging.

51. **Motors.**—The direct-current dynamo is a reversible machine, inasmuch as it can act as a motor if supplied with current from an external source. In this case it converts an electrical current into mechanical power, whereas when used as a dynamo it converts mechanical power into an electrical current.

Motors, like dynamos, may be either shunt-wound or series-wound. Motors have certain applications in medical work. The shunt-wound motor admits of better speed regulation than the series form. Small motors may easily be destroyed at starting if care be not taken to start with the safety resistance properly

* Norris and Henty, 87, Queen Victoria Street, E.C.

adjusted, and the little shunt-wound motors used for operating interrupters for induction coils and other medical purposes are sometimes spoiled through such inattention. In buying a motor it is necessary to specify the pressure of supply (in volts) from which it will be driven, the amount of power (in horse-power or fractions of a horse-power) it will be expected to exert, and, in the case of alternating-current circuits, the periodicity of the alternations must also be mentioned. Motors for use on alternating circuits are more complex machines than are direct-current motors. For an account of their construction, their advantages and disadvantages, special engineering textbooks must be consulted.

The character of the electrical supply in the different electricity supply works in the United Kingdom will be found in the Appendix. There a list is given of towns having a public supply of direct or of alternating current, with particulars of the pressure of supply, and in the case of alternating current, of the periodicity of the alternations.

52. **Alternating Currents.**—The system of distribution of electrical energy by alternating currents is in use in many places in the British Islands.

An alternating current is one which rises from zero to a maximum, and falls away again, to be followed immediately by a reversed current, which also grows to a maximum and wanes in the same manner. When a closed coil or circuit of wire is rotated in a magnetic field, the wire is traversed by an alternating current of this kind once for every complete revolution of the coil, and this recurs again and again as often as the coil is rotated, giving one cycle or period for each revolution.

Each cycle consists of two semi-cycles which are equal and opposite ; the one corresponds to the passage of the coil through lines of N. magnetism, and the other to its passage through lines of S. magnetism.

The changes in value of any regularly varying quantity, as, for example, electromotive force or current, can be represented graphically by a curved line, just as the variations in the body temperature of a patient are recorded upon the temperature charts used in clinical work.

If a horizontal line be drawn to represent periods of time, and if magnitudes of electromotive force be represented by distances above the base line (positive) or below it (negative), then an

electromotive force gradually rising from zero to a maximum of 15 volts positive, and falling again, could be represented by the curved line A, B, C (Fig. 20), and the continuation of the curve C, D, E represents a reversal in sign of the electromotive force, with a fall to 15 volts negative, followed by a return to zero, the period of time of the whole cycle being represented by the base line A, E. Similar curves could clearly be drawn to represent any values of a varying electromotive force or current, and any periods of time.

When the shape of the curve is known the electromotive force at any instant can be readily determined by plotting out the curve upon paper suitably ruled with lines (squared paper), and,

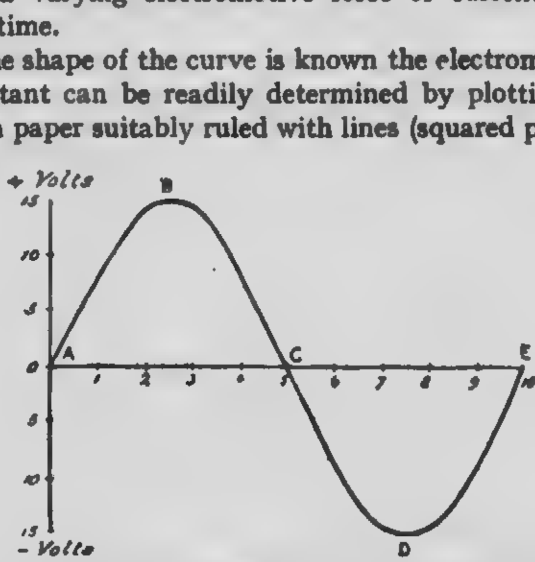


Fig. 20.—Graphic Representation of a Steadily-varying Electromotive Force.

conversely, curves can be constructed by observing a sufficient number of instantaneous values and marking them out on the paper.

The curve in Fig. 20 represents the gradual rise and fall of the electromotive force from an alternate-current dynamo machine, and may be taken as approximating closely to the current curve of an alternating system of electric light supply, and with such a curve the ratio of maximum to mean electromotive force is as 1 to 0·637, or as 1·57 to 1, if the mean be taken as unity. A curve of this kind is known as a simple periodic curve or a sine curve, and the current from an alternating-current dynamo is often spoken of as a *sinusoidal* current, to signify that it approximates in its wave form to a true sine curve.

The "frequency" of an alternating current or its "period-

icity ' means the number of periods or cycles occurring in one second.

53. **The Transformer.**—One great convenience of alternate currents is the ease with which they can be made to induce fresh alternating currents at a different voltage. With continuous currents the pressure of supply can be cut down by resistances, but by means of a transformer the pressure of supply of an alternating current can be changed into any other pressure, higher or lower, as may be desired, and that without the waste of energy which occurs in the case of resistances. Thus the energy represented by a current of 1 ampère at 100 volts can be transformed into a current of 100 ampères at 1 volt, or into a current of $\frac{1}{100}$ ampère at 10,000 volts, subject only to small

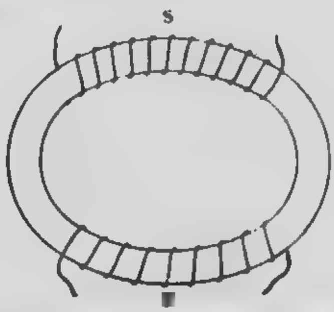


FIG. 21.—PLAN OF TRANSFORMER WITH CLOSED IRON CIRCUIT.

losses in the apparatus. Whenever the pressure of the alternating-current mains is higher than may be required in medical applications it can easily be reduced by the use of a transformer, and this should always be borne in mind.

The principle of the transformer is that of the induction of a current in a wire immersed in a varying magnetic field. A transformer consists of an iron core wound with two distinct windings of insulated wire, and thus resembles an induction coil; but no interrupter is required to produce the variations in current, as these exist already in the alternating current supplied to the transformer. The two sets of windings are called the primary and the secondary windings, and the alternating current supplied to the primary when it is connected to a system of alternate-current supply will set up a varying magnetic field, which will induce in the secondary a varying electromotive force, whose value will depend upon the ratios of the number of turns of wire

in the two coils. The coils may be wound one over the other upon a straight iron core, just as is done in an induction coil, when it is spoken of as a transformer with an open magnetic circuit, or the iron core may be in the form of a ring or rectangle, with the two coils wound upon it at different points. It is then said to have a closed magnetic circuit, as the magnetic flux set up by the current in the primary winding has a continuous path in iron for the whole of its circuit. By reason of the superiority of iron over air for the magnetic lines of force there will be an economy in giving this shape to the iron core.

CHAPTER II

MEDICAL BATTERIES AND APPARATUS

The continuous current—Commutators—The galvanometer—Interrupted currents—Medical coils—Leduc apparatus for interrupted currents—Resistances—Electrodes—Arm-bath electrodes—The electric bath—Rhythmic interrupters.

54. **The Medical Battery.**—This term is used to signify an apparatus for the production of current for medical purposes, and it includes several distinct forms of instrument. One of these is an arrangement in a suitable box of a number of small voltaic cells coupled together in series, and having a contrivance or "current collector" for varying at will the number of cells taken up into circuit with the patient.

It is also fitted with attachments or terminals for wire conductors, and should further possess a current reverser or "commutator" and a galvanometer. Such an instrument is usually spoken of as a continuous-current battery, to distinguish it from the interrupted-current battery, in which an induction coil with one or more cells for driving it takes the place of the cells grouped in series. The various fittings are fastened to a plate of ebonite, which is fixed over the cells in the box (see Figs. 22 and 23).

Special batteries are also made for furnishing current for galvano-cautery instruments and for the operation of exploring lamps, and these will require description in their proper place.

The distinction between continuous current and interrupted current is an important one in most of the applications of electric currents to patients.

The terms "continuous current," or "constant current," or "galvanic current," are applied to the current of the cells of the battery, but the current furnished by the induction coil is known as the interrupted or faradic current. The current from the cells of the battery flows through the circuit in one direction from the

positive to the negative terminal so long as the circuit is closed, and if the resistance of the circuit remains unchanged its strength is uniform, and when the circuit is broken by removing the electrodes from the patient or by opening a key, the current ceases abruptly. If the electrode be caused to slide over the

FIG. 22.—COMBINED MEDICAL BATTERY, SHOWING CURRENT COLLECTOR, GALVANOMETER, COMMUTATOR, AND SWITCH.

R, N, current reverser (see Fig. 27). G, F, switch for changing over from continuous to interrupted current, and *vice versa*. The induction coil is on the left beneath the surface, but the handles for regulating its current are seen projecting. P, S, switch for primary and secondary currents of coil.

surface of the body there will be variations of strength in the neighbourhood of the moving electrode, for the point of entry of the current, or point of greatest density of flow, will vary in position, even though the total current flowing in the circuit, as indicated by the galvanometer, be steady and uniform.

Thus the "continuous" current may be applied either in the form of a steady flow, as its name would naturally imply, or in a series of impulses produced by the operator by means of some circuit-closing or circuit-opening device; or, again, the current through any particular part can be made to vary in a gradual manner by means of the sliding movements of the electrodes, as already described. In all of these forms it is still spoken of as

FIG. 23.—COMBINED MEDICAL BATTERY.

the continuous current for purposes of convenient description, and to distinguish the current of the cells from that of the induction coil.

It is very often useful to combine the instruments for continuous and interrupted currents in one case, and such an arrangement is called a "combined battery." These combined batteries are in very general use, and are made and sold by all instrument-makers who deal in medical electrical apparatus. The figures illustrate two useful forms of combined battery.

Although it is in many ways an advantage to have the coil and the battery of cells combined in one instrument, the medical man is likely to find it convenient to have a separate portable

induction coil, as the possession of such an instrument may sometimes obviate the need for carrying about a heavy combined battery. So, too, one may obtain simple batteries of cells for continuous currents, which are often useful when it may be desired to lend a battery to a patient. For details of these batteries the instrument-makers' catalogues should be consulted.

Although they may differ somewhat in the arrangement of their parts, medical batteries are constructed upon the same general lines, and when one has become familiar with the batteries of one instrument-maker it is quite easy to indentify the working parts of other makers' instruments. A portable medical battery is required for use in the houses of patients, even though the medical man should be able to make use of the electric lighting supplies when in his own consulting-rooms.

55. **Current Collectors.**—A continuous-current battery may contain a large number of cells (20, 30, or upwards arranged

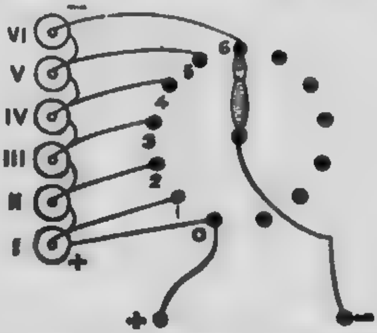


FIG. 24.—PLAN OF A SINGLE CURRENT COLLECTOR.

in series), but the number of cells to be used in different cases varies very much. On this account a ready means of altering the number of cells in circuit is required so that the current may be readily increased or diminished to suit the needs of each case. The plan is as follows: A circle of studs if fitted to the ebonite plate which overlies the cells in the box, and wires are led to these studs from the corresponding cells beneath. A moving arm can be turned so as to make contact with any of the studs, and then leads off the current from the stud which it touches.

In the diagram, Fig. 24, six cells are shown numbered I. to VI.; they are joined in series (§ 29), and from the terminals wires are led off to seven corresponding studs numbered 0 to 6. It

can be seen that a movable metallic arm springing on to stud No. 1 will throw one cell into circuit between the binding-screws, marked + and −, and similarly when the arm is placed on any other stud it brings into the circuit the number of cells shown by the figure marked against the stud.

The stud marked 0 is connected with one pole, say the positive pole of cell No. 1, and leads to a binding-screw marked +, stud No. 1 being attached to the negative pole of the same cell. When the movable arm touches stud No. 1, the current passes along it, and from there goes to the other terminal of the battery, as shown in the figure. Cell No. I. only is then included in the circuit; if the pointer be transferred to another stud, numbered, let us say, 6, then six cells are in circuit and are being used.

A more complicated current collector has been devised, by means of which the current may be taken from any cell, or any group of cells, commencing at any point. In the single collector the first cells are always drawn upon, and are likely to run down before the last cells, which are only needed occasionally. With the double collector, if six cells are required, not only could cells 1 to 6 be chosen, but cells 4 to 9, or 7 to 12, or 13 to 18, or any other set of six. With the single collector the first cells must always provide current, and cell No. 12 can only be used when eleven cells are insufficient. Accordingly, with a single collector the last cells of the series are very seldom called on at all, while the first cells have to do duty every time the battery is used. Another advantage of the double collector is that with its aid the working of every cell of the battery can be separately tested. If in the figure of the single collector (Fig. 24) the positive terminal of the battery be not joined to stud No. 0, but to a second arm, pivoted on the same axle, but electrically insulated from the first one, and capable of independent movement (Fig. 25), and if this second arm be joined to the positive terminal, it can be seen that with the two arms on the studs 3 and 6 the current would be taken from cells 4, 5, and 6 only—that is to say, the group of cells 4 to 6 would supply the current to the circuit. In like manner any number of consecutive cells from one upwards could be picked out from any part of the whole series. It is usual for one of the arms to carry a circle so divided and numbered as to read off directly the number of cells in use.

The studs of current collectors must be of good size, and the

pointer just broad enough to touch two at once, in order that the number of cells in the circuit may be increased or diminished without breaks of current and unpleasant shocks at the change from one stud to the next. At the same time care must be taken that the movable pointer of any collector is not left for any length of time in contact with two studs at once, for when it is in that position one cell is short-circuited, and its energy is being wasted. This waste can be reduced by the use of a collector having an arm split longitudinally with its two portions joined through a resistance of fifty ohms.

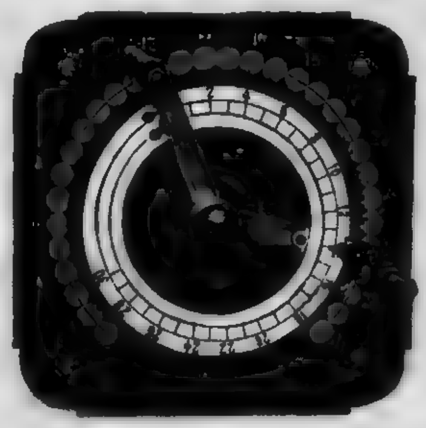


Fig. 25.—Double Collector.

56. **The Commutator or Current Reverser.**—An apparatus for reversing the direction of the current in the external portion of the circuit is indispensable for some medical purposes. It is difficult to make a satisfactory examination of the reactions of nerve and muscle without one.

Ruhmkorff's commutator (Fig. 26) consists of a cylinder of vulcanite M, having at each end a metal cap or ferrule, C, D, and supported between two uprights in such a way as to revolve easily about a horizontal line ; each end is connected to a binding-screw A, B, and each metal cap is prolonged in the form of a cheek, E, F, along one side of the vulcanite cylinder for two-thirds of its length. On either side of the cylinder, springing against it, are two pieces of metal I and L, connected with the terminals of the battery. When the cylinder is turned by means of the handle Z, either of the metal cheeks can be brought into contact with each of the springs, I, L. The positive pole of the

battery connected, say with L, can thus be brought into connection with either the binding-screw at A or at B, so that the current can be made to pass in either direction at will round the external portion of the circuit between A and B. The + and − signs on the vulcanite cylinder indicate the polarity of the

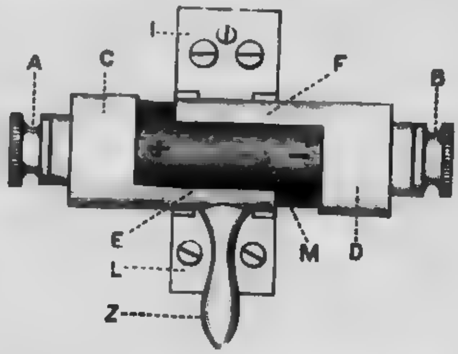


FIG. 26.—COMMUTATOR OF RUHMKORFF.

binding-screws. In the position shown A is positive; a half revolution of the cylinder alters A to negative, and therefore the reverse side of the cylinder, which then comes into view, will have the + and − signs transposed also.

Another form of commutator is shown in Fig. 27. In this the

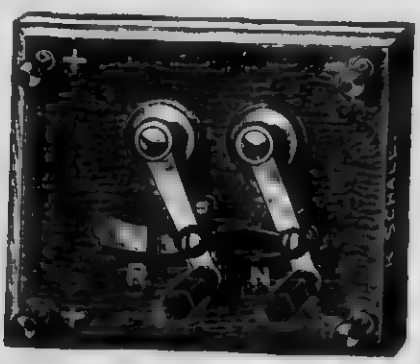


FIG. 27.—DE WATTEVILLE'S COMMUTATOR.

two crank arms move together. In the figure N stands for normal, R for reversed. These commutators also serve as interrupters of the circuit.

57. **Galvanometers.**—The older types of galvanometers are now superseded in medical practice by newer forms of instru-

ment of the d'Arsonval pattern, or of some modifications of it. These have the advantage that they can be used either in a horizontal or vertical position. They are independent of the earth's magnetism, and therefore do not require to be set in the magnetic meridian (§ 40), nor are they affected by the proximity of iron or of stray magnetic fields in their neighbourhood. They are also dead-beat—that is to say, the pointer indicates its readings without preliminary oscillations. Thus time is saved, and the patient spared the inconvenience of having to bear a possibly painful current while the operator is waiting for the oscillations of the needle to settle down, in order that he may obtain a reading of the milliampèremeter.

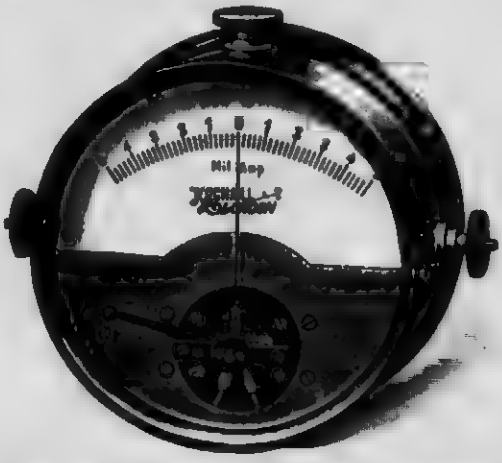


FIG. 28.—D'ARSONVAL MILLIAMPÈREMETER.

In the d'Arsonval instruments the movements of the needle are controlled by placing it in a strong magnetic field between the poles of a horse-shoe magnet. In the modified "moving-coil" instrument the magnetic needle is replaced by a slender coil of wire which carries the current, and so acquires magnetic properties (§ 38). It is so suspended as to be free to move, and a spring attachment brings it back to zero again. The general appearance of these instruments is shown in Fig. 28. They may be obtained as milliampèremeters, as voltmeters, and as ampèremeters, and can be constructed to read within any range likely to be required in medical practice.

In the case of horizontal galvanometers of the ordinary type, the position which the needle takes up when a current is flowing

through its coils is the resultant of two forces—viz., the attraction of the earth's magnetism tending to hold the needle in the magnetic meridian, and the attraction of the field of force of the coils tending to draw it into a position at right angles to this. Changes in the magnetism of the needle do not alter the relation which the two opposing pulls bear to one another, and therefore the deflections of the needle are not altered if the magnetism of the needle becomes diminished, as may be the case with the lapse of time. This makes the horizontal galvanometer trustworthy for use as a standard instrument.

Before use all horizontal galvanometers must be so placed and levelled that the needle comes to rest at the zero of the scale, and swings freely about that point.

The working range of a galvanometer is increased by the use of a shunt circuit for diverting a known fraction of the current from the coils of the instrument. Fig. 29 shows the arrangement.

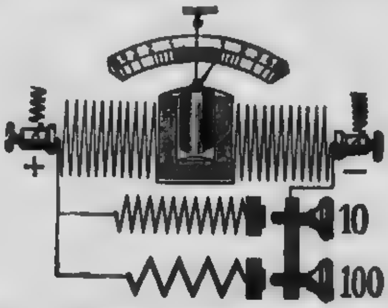


FIG. 29.—PLAN OF SHUNT CIRCUITS OF A GALVANOMETER.

Between the binding-screws, marked + and −, the galvanometer coils are represented. Two other paths are shown beneath, either of which can be completed at the points of their respective screws; both of them have a lower resistance than the circuit of the galvanometer coils, and when closed they convey nine-tenths and ninety-nine hundredths respectively of the current, while the remaining tenth part or hundredth part traverses the galvanometer coils and produces its proper deflection. But if the deflection is known to be due to one-tenth of the current only, then to get the total current the indicated reading must be multiplied by ten, and the same for the other or 100 times shunt.

Both shunt circuits are not to be closed at one time.

By means of a battery and a resistance-box it is easy to verify

the readings of a galvanometer, and to determine whether the shunts work correctly.

58. **Ammeters and Voltmeters.**—Ampèremeters or ammeters are sometimes needed by medical men for measuring larger currents than those for which milliampèremeters are used. In general an ammeter has a very low resistance, and must not be coupled direct to the terminals of an accumulator or to the main supply. If this is done the instrument may be destroyed at once. The proper way is to connect it in series with the instrument or apparatus the current through which it is required to measure. Voltmeters, on the other hand, generally have a high resistance, which protects them from overheating unless they are misused, and they may be connected directly to the terminals between which the electromotive force is to be measured.

A very convenient way of measuring the electromotive force of a medical battery is to use its own galvanometer as a voltmeter. Supposing the resistance of the galvanometer to be 25 ohms, and a resistance coil of 975 ohms to be connected to the terminals of the battery, the total resistance in the external circuit will be 1,000 ohms.

Now, one volt acting upon a resistance of one thousand ohms will cause a current of one-thousandth of an ampère to flow—that is to say, one milliampère. With five volts, five milliampères, and so on. The readings of the galvanometer in milliampères will, therefore, express the electromotive force of the battery in volts if the resistance of the circuit amount to one thousand ohms; any correction for internal resistance of the cells themselves may usually be disregarded. This method has the advantage of measuring the electromotive force under conditions of resistance like those for which the battery is to be used.

Instrument-makers can usually supply a resistance coil properly wound to bring up the total resistance of the galvanometer circuit to a thousand ohms, in order to simplify this mode of measuring the electromotive force of the cells of a medical battery. With this it is very easy to test the voltage of the individual cells, by taking readings of the galvanometer while switching on the cells one after another. Each cell may be taken separately if the battery have a double collector (§ 55); if it have a single collector, the increase of reading for each cell added may be taken to represent its electromotive force. If the resistance coil available do not bring the resistance of the circuit

to so simple a figure as 1,000 ohms, the method can still be used by applying a simple calculation based on Ohm's law (§ 42).

The expansion of the wire when heated by the passage of a current may be used as a measure of the current, or by suitable graduation of its scale it may be made to read directly in volts.

Fig. 30 shows the construction of a "hot-wire" instrument. C is the wire stretched between H and K by a spring F. A thread attached to its centre passes round B to a spring A. When the wire expands the pull of A deflects it, and the movement is communicated through B to the pointer E.

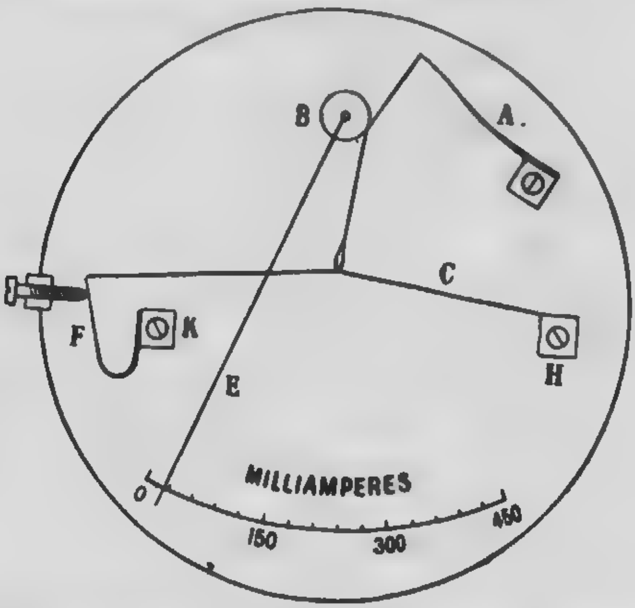


FIG. 30.—ARRANGEMENT OF "HOT WIRE" INSTRUMENT, CALIBRATED AS A MILLIAMPÈREMETER.

59. **Interrupted Current — The Medical Coil.** — In medical practice the induction coil has been universally adopted as the source of interrupted currents, but it is necessary to point out that the current of an induction coil is a special form of interrupted current of some complexity. The coil is useful because it affords a convenient means of producing sensory and motor effects at small cost. For purposes of stimulation it serves admirably, and in so far as electrical treatment consists in the simple stimulation of living tissues the induction coil is a valuable appliance. Its use for accurate work, however, has the drawback that the

currents of different coils vary much in character, while their measurement with any certainty is impossible in practice.

The variety of coils in the market is very great. Usually they are fitted up in a box with one or two dry cells to drive them, and with a drawer to hold wires and electrodes; this is convenient, as it makes them portable. An inspection of an instrument-maker's illustrated catalogue, or better still of his stock, is the quickest way of becoming familiar with the types of coil in general use.

In order that the coil may be used for medical purposes, there must be some method of regulating its strength. The following methods are in actual use in medical coils:

1. By the use of a sliding core to vary the strength of the magnetic field.

This method requires the use of an auxiliary electromagnet to operate the interrupter, and that arrangement gives irregular currents of low frequency, particularly when the weight of the hammer is great or when it vibrates in a vertical direction. The shocks from coils so fitted are unpleasant, and they are bad instruments for electrical testing, and for most kinds of electrical treatment.

2. By the use of a movable secondary coil (sledge coil), which can be brought into stronger or weaker parts of the magnetic field of the instrument.

This method of regulation is a good one; it gives a wide range of current strength, but is only suitable for regulating the secondary current. As with a good secondary coil there is little or no advantage to be gained from using the primary, the drawback is unimportant.

3. By the use of a metal tube to slide over the iron core and shield the coils from its magnetic action through the effect of the tube as a closed conducting circuit. The method hardly gives a sufficiently wide range of current strength. The shielding effect is best seen with a tube of thick copper.

4. By using a resistance to vary the current in the exciting circuit.

5. By a switch for bringing into action a greater or lesser number of turns of the secondary winding.

This method gives regulation in steps, and may not allow of sufficiently fine adjustment.

6. By the use of a variable resistance in the secondary circuit.

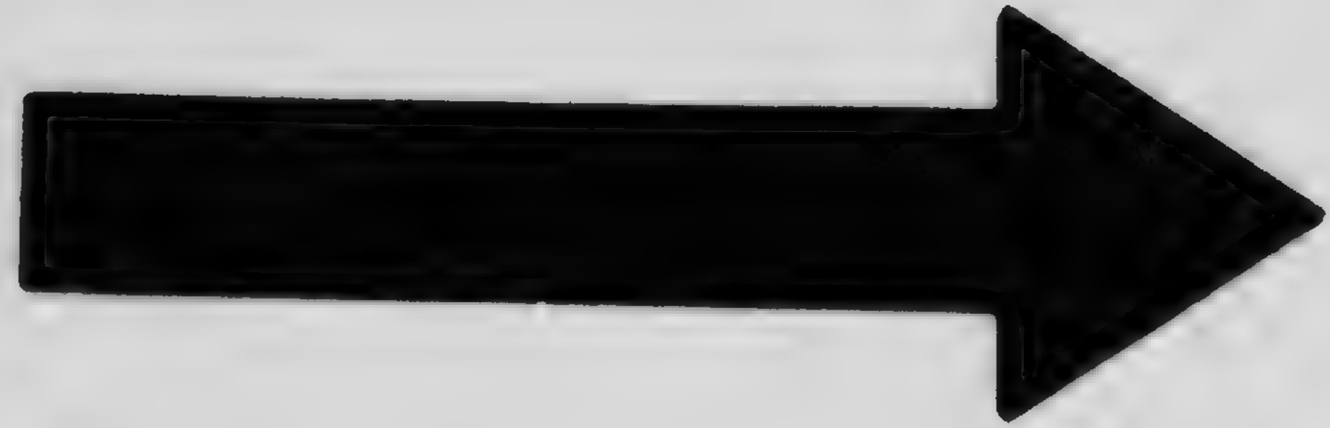
Methods 1, 3, and 4 regulate both the primary and secondary circuits, the others regulate the secondary circuit only.

In choosing a coil it is important to see that the interrupter works smoothly, for many coils are defective in this important respect, and give irregular shocks, which are very unpleasant. Before buying, it is a good plan to set the coil in action, and to test it upon the hand or cheek. A good interrupter gives out a smooth musical note. It should not make a clattering sound. It is a convenience to choose a coil which is driven by a dry cell, as these cells give the least trouble.

The character of the discharges of an induction coil are modified by the number of turns of wire in the secondary windings. A coil of few turns (two or three hundred) has a lower electromotive force and a lower resistance than a coil of many turns (two or three thousand), and besides its resistance there is another factor which increases with the number of turns, and is known as its self-induction ; this retards the rate of rise and fall of current in the coil, and diminishes the magnitude of the current which can be taken from it. Thus a coil of many windings has a high electromotive force so long as very small currents are taken from it, but this falls rapidly when the resistance of the external circuit is low. A short coil has a lower electromotive force, but is capable of giving a proportionately larger current with less fall in its electromotive force. For treatment with moistened skin and wet electrodes a long coil is not needed, but for the stimulation of the superficial cutaneous nerve endings with a dry skin and a wire brush—a method sometimes, though rarely, adopted—a long coil is needed, as the dry skin has a very high resistance, and requires a high electromotive force to drive through it even the small current which can be borne in this mode of treatment. Some medical coils are therefore provided with two interchangeable secondary coils ; but the same advantage can be had from a single coil if its windings are tapped so that either the whole or a part can be used at will.

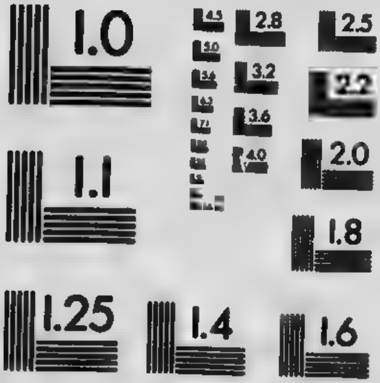
Fig. 31 shows a simple form of portable medical coil which answers all requirements, and has its secondary coil subdivided so that one-third of the windings forms a short coil secondary, while the effects of a long coil can be had by using the whole of the windings.

Duchenne long ago maintained that the physiological effects from long windings (secondary)were not identical with those from



MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



short (primary). At that time electrical science could offer no explanation of this. It was suggested that the difference was a matter of electromotive force, which is greater with a long secondary. This did not satisfy Duchenne, because the differences observed by him were independent of the mere strength of the electromotive force or current. Differences in these points may be adjusted, and were adjusted by him, but the innate differences in quality remained in spite of adjustments. The essence of Duchenne's contention was this, that the ratio of motor to sensory effect was not identical in the two types of coil, and that with long coils (secondary) the sensory effects were strong at weak degrees of motor effect, while with short coils (primary) the opposite was the case.

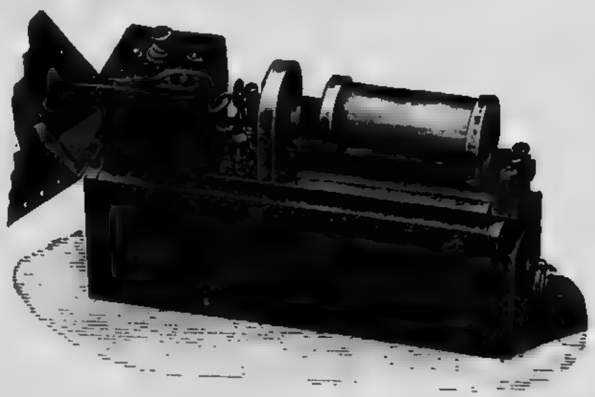


FIG. 31.—PORTABLE SLEDGE COIL, WITH SUBDIVIDED SECONDARY WINDING.

60. **Measurement of Induction-coil Currents.**—Some of the methods of comparison or measurement which have been proposed for use with medical coils deserve to be mentioned. The oldest is that proposed by Du Bois Reymond, and still in general use in physiological laboratories. In this the secondary wire is wound on a separate bobbin (sledge coil), which can be moved to and fro along guides so as to bring it nearer to, or further from, the primary coil. A millimetre scale on one of the guides, or on the base board of the apparatus, serves to mark the relative positions of the two coils, and the measurements are made in millimetres of distance. The method is of some use when applied to identically wound coils which are identically excited, though variations in the action of the hammer are not taken into consideration, whereas these may be of considerable importance.

The measurement of the electromotive force and current of the "primary" circuit is complicated by the influence of the battery which drives the coil, and which exerts its own proper action upon any measuring instrument which may be put into the circuit. Reference to Fig. 16 will show that the current induced in the primary circuit is led off by two branch wires which come from the two ends of the primary windings. The patient, therefore, is in shunt to the exciting circuit when connected to the terminals at P, and a galvanometer connected up in his place would carry some of the battery current. The secondary coil, however, is an independent coil, and the effects of induction in it can be measured, though not by an ordinary galvanometer. With such an instrument the alternate impulses from the coil tend to deflect the needle first in one direction and then in the other, with the result that the needle either remains quite still or else oscillates about its position of rest. If the magnetic needle be replaced by a small bundle of fine soft iron wires, these have no magnetic polarity, and will be attracted by the coils of the instrument quite independently of the changes of direction of the current in the coils, and by means of such a soft iron bundle steady deflections are obtained with the currents of a secondary coil.

Mr. Giltay of Delft, Holland, has made an instrument* on this principle for use with medical coils. In it a bundle of soft iron wires are suspended between a pair of coils in a position at an angle of 45 degrees with their axis. When a current traverses the coils, the core tends to set itself in the axis of the coils, and its movements are made visible by means of a scale and pointer.

Dr. S. Sloan of Glasgow has designed a "Faradimeter" for the measurement of the currents of medical induction coils. His instrument is more convenient than that of Giltay in several respects, particularly in simplicity of construction and in portability. The moving part in this case is not a bundle of soft iron wires, but is a suspended and freely-moving fine wire coil. An account of this instrument will be found in *The Journal of Physical Therapeutics*, vol. iii. (April, 1902).

The electromotive force of an induction coil can be best measured by an instrument invented by Lord Kelvin, and known as an electrostatic voltmeter. It is based upon the mutual attraction of two bodies oppositely electrified, and has

* *Ann. der Physik und Chemie*, Bd. 50, Leipzig, 1893 (figure).

the advantage of using no current, and therefore it measures the electromotive force of the coil on open circuit, subject to corrections for the capacity of the voltmeter. When the circuit of an induction coil is closed, the voltage at its terminals falls away rapidly, particularly if it be closed through a low resistance.

A particular secondary coil was tested by means of an electrostatic voltmeter, and the potential difference at its terminals on open circuit was nearly ninety volts, but when the circuit was

FIG. 32.—THE SLOAN FARADIMETER.

closed through a resistance of 1,000 ohms, in shunt to the voltmeter, the potential difference registered was only ten volts.

This observation shows the importance of measuring the electromotive force of a medical coil under conditions resembling those under which it is to be used, and teaches us that some coils with long windings may appear to have a much higher electromotive force than they actually possess under conditions of use.

In all these methods of measuring induction-coil currents we find ourselves face to face with a physiological difficulty, which

is that the measuring instruments indicate the mean current of the apparatus, but the motor and sensory responses of living tissue to varying currents are not proportional to the mean current.

The physiological response is proportional, not to the mean current or average current, but rather to the maximum current, and to its rate of change or its suddenness of rise and fall. It follows, therefore, that it is not enough to know the mean current or mean electromotive force of a coil unless the maxima and the rate of change can be deduced from them. When the shape of the curve of a current is known the maxima can be calculated from the observed magnitudes of the mean current (§ 52), but if the shape of the current curve is unknown or irregular, then readings of mean current or mean electromotive force are not a sufficient indication of the physiological effect.

In the case of medical induction coils in general the shapes of their curves of current are both diversified and inconstant, and even for any single coil the determinations of its characteristics which might be made on one day could not be depended upon to recur unaltered in the next.

61. **Current Curves of Coils.**—Many curves have been drawn from time to time on theoretical g ds to represent the discharges of induction coils, and actu tracings have also been taken. Previously to 1894 some curves were published by Dr. Kellogg,* and his method of doing so by means of an instrument devised by himself is fully described in his paper, which is a valuable contribution to our knowledge of the medical coil.

We have already seen that the secondary-coil current is alternating in direction with its two semiphases unequal. The greater the number of the secondary windings the longer will be the total duration of each impulse of current. At a slow speed of the interrupter the make and the break discharges are distinct from one another with intervals between them. At a more rapid speed the discharges will follow each other without any period no current between them, and with still more rapid interptions the make and the break waves will interfere with each other.

The accompanying tracings of the secondary discharges of induction coils throw light upon the differences observed by

* "The International System of Electrotherapeutics," edited by Dr. Bigelow (F. A. Davis and Co., Philadelphia, 1894).

Duchenne between the physiological effects of short primary and long secondary coils. They show that the durations of the impulses are longer with long secondary windings than with short, and that the presence or absence of the iron core also has a great effect upon the length of the current waves.

The tracings are taken with a Duddell's oscillograph on a moving photographic plate. The speed of the plate is uniform in all the tracings represented, and this permits of measurements of the duration of the different current waves, and also of their direct comparison, so far as times are concerned. The length of each of the succeeding tracings represents about $\frac{1}{35}$ second. They run from left to right. In Fig. 33 the curve of the exciting current (E) in the primary coil is shown above that of the secondary (S). In Figs. 34, 35, and 36 it is below. In all the curves of the secondary coil the wave at break is above the base line, and the wave at make is below it.

FIG. 33.—IRREGULAR DISCHARGES, DUE TO FAULTY ACTION OF INTERRUPTER.

S, secondary curve; E, exciting current.

Fig. 33 shows that the vibrating hammer interrupter is apt to be a defective device, and does not always produce clean, sharp makes and breaks. In the tracing six inadequate attempts at contact can be counted before the proper establishment of the steady flow at make, while at the break of circuit there are also two irregularities.

As each of these partial contacts is reflected in the curve of the secondary circuit, it is thus seen that the secondary current of a coil so fitted is of great complexity, and one finds in practice that it is highly disagreeable. The rate of this type of interrupter is slow. In the figure each interval lasts 0·025 second, and each impulse about 0·016 or more; the whole cycle, therefore, occupies 0·04 second, a frequency of 25 per second, which is not very suitable for medical applications.

Induction coils with auxiliary electromagnets for operating the hammer give these irregular currents of low frequency.

Fig. 34 shows the character of the current waves of a coil with a long secondary when the iron core is removed. The lower curve shows the growth, the period of steady flow, and the abrupt rupture of the exciting circuit, while the upper shows the currents induced in the secondary coil. It is easy to see which one of the waves corresponds in time to the make and which to

FIG. 34.—CURRENT CURVES OF COIL WITH LONG WINDINGS, BUT WITHOUT CORE (MECHANICAL INTERRUPTER).

S, secondary curve; E, exciting current.

the break of the exciting circuit; the former starts less abruptly from the zero line, and is a lower wave than the latter. Their durations as measured are about 0·0025 second, the frequency of the interruptions in this particular instance being one of 80 per second.

In Fig. 35 everything is as before, except that the iron core has been inserted. The change in the contours of the tracings

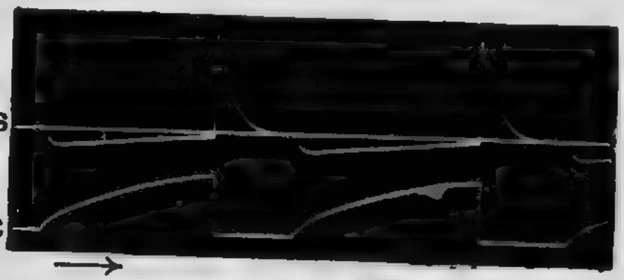


FIG. 35.—CURRENT CURVES OF COIL WITH LONG WINDINGS, AND WITH IRON CORE

S, secondary curve; E, exciting current.

is profound, for the wave of current at break now lasts half as long again (or about 0·0037 second), while the current at make is prolonged to more than 0·01 second—that is to say, it has a duration nearly three times as long as was the case when no iron core was present.

It is also instructive to compare the lower curve which represents the exciting current. Its rise is slow, so slow that it has not reached the steady state at the moment of rupture, although the rate of interruption is a slow one.

Another interesting point is the effect of alterations in the speed of the interrupter. As would naturally be expected from the duration of the waves, a speed can be reached at which the waves at make and at break begin to tread upon each other's heels, so to speak, so that before the make wave is over it is suddenly reversed by the wave at break, and *vice versa*. Fig. 36, from the same coil, shows this point clearly.

FIG. 36.—INTERFERENCE OF CURRENT WAVES WITH RAPID INTERRUPTIONS.

S, secondary curve ; E, exciting current.

The extent of the interference of the two waves of current depends upon the character of the cc tact-breaker, and varies in different coils. The more rigid the ɔring the more likely it is that the rebound or break will follow too quickl upon the make. The shocks of an induction coil can often be very considerably altered in character by a little adjustment of the contact-screw, because changes in its position may alter the play of the spring, and so make a difference in the way in which it rebounds after contact. This change in the action of the interrupter can often be recognised by an alteration in the note or sound which it gives out. Again, the interference of the current waves will be more readily produced when these are long than when they are of short duration. Thus a coil with long windings nd a heavy core must be worked at a lower rate of interruption han is permissible with a short coil, if it is wished to keep the waves of current separate.

The length of the primary winding is also a factor, for the self-induction of a long primary will exercise its own retarding effect upon the growth and decay of current.

Thus for painless muscular stimulation the best construction

would be one with short windings both in primary and secondary, with no iron in the core, and with a mechanical interrupter. The best frequency of impulse for muscular stimulation has been determined by Leduc as that of 100 interruptions per second, with durations for the individual waves of one-thousandth of a second, and with intervals nine times as long.

As induction coils must have an iron core if they are to be operated by the ordinary vibrating spring contact-breaker, we

FIG. 37.—CURRENT CURVE OF WELL-CONSTRUCTED COIL, USING ONE-THIRD OF THE SECONDARY WINDING.

are at once confronted by a constructional difficulty, and must inquire afresh as to whether it is possible to employ an iron core and still to obtain waves of short duration. The answer to this is in the affirmative if pains be taken in the general design of the instrument, and the interrupter is light and springy.

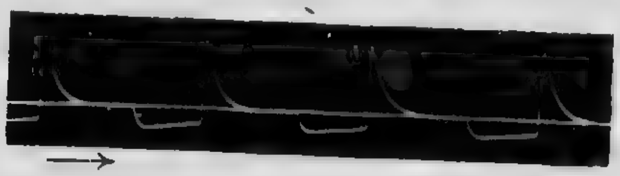


FIG. 38.—CURRENT CURVE OF SAME COIL, USING THE WHOLE SECONDARY COIL.

Figs. 37 and 38 show the curves of secondary current in the case of a coil having a slender core of about twenty-four iron wires, which is sufficient for the automatic operation of the interrupter.

From these we see that the waves of a well-constructed coil may be very short, and that the good points of such a coil are not seriously impaired by the presence of a small amount of iron in the core. The curve shown in Fig. 37 possesses just the characteristics advocated by Leduc, except that the frequency is not quite that of 100 per second. These tracings are taken

with the coil represented by Fig. 31, a form of coil designed empirically by myself some years ago, and constructed by Mr. Schall. It is interesting to note that this coil has found much favour with the medical profession, and is made and sold in considerable numbers, doubtless by reason of the agreeable character of its current.

62. **Sensory Effects of Coil Currents.**—It may be asked why an alternating current from a dynamo is not used for purposes of testing in order to escape the uncertainties of the induction coil, and the answer to this question is one of considerable interest. So far as measurement goes, the use of the sinusoidal current of the electric light mains for purposes of testing would be most convenient, because, as we have seen, the shape of its current curve is uniform and regular (§ 52), but unfortunately it produces, when used in the ordinary way in medical applications, a stinging effect upon the sensory nerves which interferes seriously with its use. This particular point helps to provide an explanation of the phenomenon observed by Duchenne that the current of the secondary coil has a greater effect upon sensory nerves than the current of the primary coil, and of the well-known fact that secondary coils of different construction produce very different degrees of painful effect.

The duration of each discharge of an alternating current having the not uncommon periodicity of 100 is one two-hundredth (0·005) of a second, and that of the secondary circuit of a coil may have a somewhat similar duration.

In 1903 Dr. Henry Head observed that a great change was produced in the sensory effect of a certain type of coil by withdrawing the iron core. The current when the core was inserted was of a disagreeable character, but was free from this character when the core was withdrawn, and this difference in quality was found to be quite independent of the actual strength of the current, as estimated from the degree of muscular contraction set up.

In discussing the matter with him I suggested that the explanation might be found in the greater duration of the current waves when the iron core was inserted, and soon afterwards Dr. Head was able to obtain some oscillograph tracings of the currents of his coil which confirmed that suggestion by showing that the insertion of the core which increased the painfulness of the current also increased the duration of the current

waves. It was this interesting discovery which has led to our investigation of the current waves of various coils by the oscillograph method. The tracings obtained, some of which are figured above, show conclusively that the current waves of medical coils in common use may range in duration from one two-hundredth to one thousandth of a second (0·005 to 0·001) for the currents at break. The impulses at the "make" may be even longer, but as they are usually of much lower electromotive force, they produce an effect which is negligible.

The conditions under which long waves are produced are the conditions associated with a high degree of self-induction, and this is greatest in coils with long lengths of wire in the primary and secondary windings, and in coils with much iron in the cores. When the interrupter is operated by an auxiliary electro-magnet in the circuit the self-induction of the whole circuit is notably increased, and shows itself in the increased length of the waves, the wave of current at "make" in the secondary circuit being especially long under these circumstances.

The effect upon the contraction of striped muscle seems to be alike for long and for short waves w[illegible] the limits existing in the discharges of medical coils. The effect on sensation, on the other hand, is very greatly influenced by the length of the waves. Thus waves with a duration of 0·005 second (one two-hundredth of a second) possess the stinging painful quality in a high degree, and this decreases as the waves grow shorter, being slight for wave-lengths whose duration is less than one four-hundredth (0·0025 second) of a second. The production of sensation by currents is a matter of the transportation of ions. With the short waves the movement of ions is relatively small, and therefore the stimulation of the sensory nerves is also small. It is for this reason that the sinusoidal current of the electric lighting mains is too painful in its effect to be suitable for use in electrical testing as a substitute for coil currents.

63. **Mechanical Interrupters.**—When the question of the use of coil currents in diagnosis is examined, we find that there is no apparent reason why interrupted currents from other sources should not be used in their stead. Dr. S. Leduc (Nantes) has recently called attention afresh to this matter, and by using a continuous current source and a mechanical interrupter, he has shown that all the effects upon muscle which are generally considered to be peculiar to the induction current or "faradism,"

as it is commonly called by medical men, can be produced by means of a battery current mechanically interrupted.

Leduc's apparatus consists of a revolving commutator driven by a small electric motor. By an ingenious arrangement of collecting-brushes the circuit is closed for a certain fractional part only of each revolution of the commutator. With this apparatus the number of impulses per second can be varied by varying the speed of revolution of the motor, and their duration—that is to say, the period during which the circuit is closed in each revolution—can be regulated by moving the position of one of the brushes. Working with this apparatus Leduc has found that for the rate of one hundred intermittences per second the best physiological effect corresponds to durations of time of current flow of one-thousandth of a second, with nine-thousandths of interval, and any increase or decrease from these proportions of time of current flow requires an increase in the electromotive force needed to produce a minimal muscular contraction. With this apparatus the rise and fall of current is more brusque or sudden than with alternating currents from a dynamo or from an induction coil.

Its advantages are as follows : The current used in testing can be measured directly in milliampères ; the volts applied can be measured equally well if desired, the frequency of the interruptions can be regulated and measured in a moment by the addition of a speed-counter, and, finally, the painful effect upon the sensory nerves of the patient can be reduced by the device of using impulses of very short duration. This instrument is bound to supersede the induction coil altogether when exact work and measurement of results are wanted, although, no doubt, the coil will continue to hold its ground for a long time to come as a means of producing simple excitation of nerves and muscles.

Leduc, in describing his apparatus,* writes as follows : "To obtain the interrupted currents I use an interrupter driven by a small motor. An insulated disc is mounted upon the axle, and is fitted with four metallic segments, the opposite segments being connected together to form two pairs (Fig. 39). A pair of brushes is provided, and the circuit is closed from brush to brush through the segments. If the contacts of the brushes with the two segments composing a pair occur simultaneously, the current is only interrupted during the short moments during

* *Arch. d'Élect. Médicale*, September 15, 1903, p. 521.

which the brushes are passing over the intervals which separate adjoining segments. One brush is fixed, and the other is movable through an arc of 90 degrees, and by a displacement of the movable brush one can so arrange matters that the circuit only becomes closed when one segment of the pair has already performed a half, three-quarters, or more of its passage under the fixed brush, in which case the current can only get through during one-half, one-quarter, or less of the whole period. The speed of the motor is regulated by a rheostat, and this determines the number of interruptions in a given time. The speed of rotation can be measured directly by a speed-counter on the axle. A milliampèremeter in the circuit measures the current,

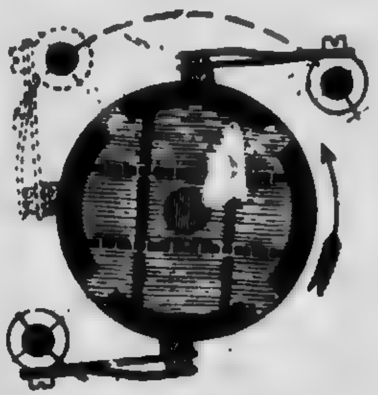


FIG. 39.—PLAN OF COMMUTATOR OF LEDUC.
The dotted lines show the range of movement of the upper brush-holder.

but for correct values it is necessary to compare the readings indicated when the motor is in movement with those indicated when it is at rest. The latter give the true values, and the former can be used as a measure of the duration of the time of passage of the current during each period. If the word 'period' is taken to mean the time between one interruption and the next, the current can pass and be 'on' during one-half, or one-fifth, or one-hundredth of the period, and be interrupted and 'off' during the remainder of the period. Thus if the current passes during one-tenth of a period and is off for the remaining nine-tenths the current registered by the milliampèremeter when the commutator is rotating will be the tenth of the true current. By thus comparing the currents indicated with the commutator

at rest and in motion one can estimate the duration of time during which the current is flowing."

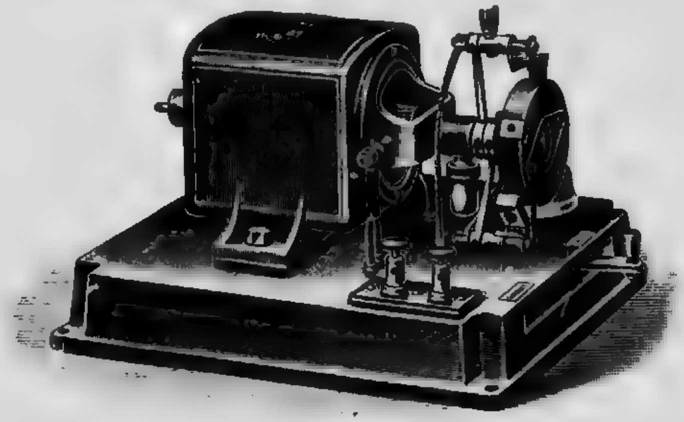


FIG. 40.—LEDUC'S MECHANICAL INTERRUPTER.

Fig. 40 shows a motor fitted with a commutator like that of Fig. 39 and a hinged brush-holder for varying the duration of

FIG. 41.—MOTOR-DRIVEN INTERRUPTER WITH SPEED-COUNTER AND ADJUSTABLE BRUSH-HOLDER.

the individual contacts, and Fig. 41 shows another similar instrument, which also has a speed-counter, which is a very necessary addition for experimental work.

The tracing in Fig. 42 is that of a series of unidirectional impulses of current from a mechanical interrupter, and Fig. 43

shows alternating impulses produced in a similar way. These figures are from actual tracings taken with the oscillograph. In both the ratio of length of impulse to length of interval

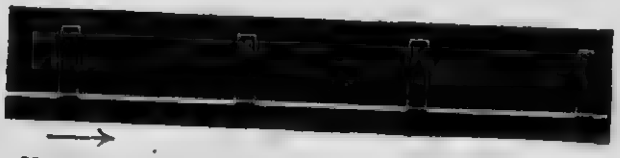


FIG. 42.—UNIDIRECTIONAL CURRENT WAVES PRODUCED MECHANICALLY.

is to be noted, and it is to be remembered that by moving the brush-holder the impulses can be made longer or shorter at the expense of the interval without increasing their frequency.

FIG. 43.—ALTERNATING CURRENT WAVES PRODUCED BY A MECHANICAL INTERRUPTER.

The frequency is varied by changing the speed of rotation of the apparatus. In these figures, too, the whole tracing represents a time of one twenty-fifth of a second.

64. **Regulation of Current—Resistances.**—When the current is regulated as described in § 55, it will be seen that, neglecting the resistance of the battery, the electromotive force is the only thing altered in the circuit. But by Ohm's law we know that the current is numerically equal to the electromotive force divided by the resistance of the circuit, so that it might be regulated by introducing or removing resistances, the electromotive force being kept constant. In some cases it is more convenient to regulate by this method, as, for example, in regulating the current from the electric light mains, in which the electromotive force is maintained at a constant figure. An adjustable resistance for varying the current in a circuit is sometimes called a "rheostat." In general, with batteries, when the total resistance of a circuit is large, it is more convenient to alter the electromotive force than the resistance in the circuit. Thus, suppose a

circuit has a total resistance of 3,000 ohms, and is acted on by twelve cells of 1·5 volts each, there will be a current of 6 milliampères; if now it is required to double the current, it is easily done by adding twelve more cells, taking for granted that their internal resistance may be neglected, but if it were desired to make the alteration by reducing the resistance of the circuit it would be necessary, in order to double the current, to take out a resistance of 1,500 ohms, which may not be convenient. When it is desired to increase current by taking out resistances, it is of course requisite that the resistances to be removed must have been connected up in the circuit before the commencement of the operation. If the total resistance is small this can be done, and in such cases the current is most easily governed by variable resistances in the circuit. Thus, suppose a circuit made up of a cautery burner whose resistance with its leads amount to 0·01 ohm, and an accumulator whose electromotive force is two volts and internal resistance 0·002 ohm, the current would be well governed by having a variable resistance of half an ohm in the circuit. When the current was turned on with full resistance, it would amount to about 3·9 ampères, and by reducing the variable resistance to 0·088 ohm a current of 20 ampères would be given, which would probably suffice to heat the burner.

It must be borne in mind that a resistance, suitable for regulating small currents, may be burnt and destroyed if large currents are allowed to traverse it, also that a resistance of one or two ohms may be ample for regulating a lamp or cautery, but will exercise no appreciable regulating effect upon a circuit of high resistance. In general a rheostat should have a resistance approximately equal to that of the circuit which it is to control.

In medical treatment it is more important to have a resistance which can be smoothly adjusted while the current is passing than one which is graduated exactly in ohms.

A useful form of rheostat is shown in Fig. 44, where a movable arm is made to touch successively upon a series of metal studs which are connected behind to a resistance whose value is shown by figures marked opposite the studs.

A form of resistance coil that will frequently be found useful is one which is known as the "wire rheostat" (Fig. 45). It is very convenient in cases such as the example given above, in which there is a small external resistance only in the circuit, and a large current is to be regulated. It usually consists of a coil

of moderately thick uncovered German silver wire. The current is led in at one end of the helix, and leaves it by a metal traveller sliding on a metallic arm joined to the other end of

FIG. 44.—ADJUSTABLE RESISTANCE FOR MEDICAL USE.

the coil. The resistance interposed is easily seen to be proportional to the number of turns of the wire between the end attached to the terminal and the sliding piece. The form of this

FIG. 45.—WIRE RESISTANCE WITH TRAVELLER.
S, strong; W, weak.

resistance is favourable to cooling, as the wire is freely exposed to the air. It is especially useful for regulating the current in cautery or lamp instruments.

FIG. 46.—GRAPHITE RHEOSTAT.

A very useful form of adjustable rheostat for high resistances and small currents is a sliding graphite resistance (Figs. 46 and 47). It consists of two parallel pencils of graphite, with a metal

bridge to slide between them in contact with both. As the position of the slide is altered a greater or less length of the badly-conducting graphite is brought into the circuit, and the resistance

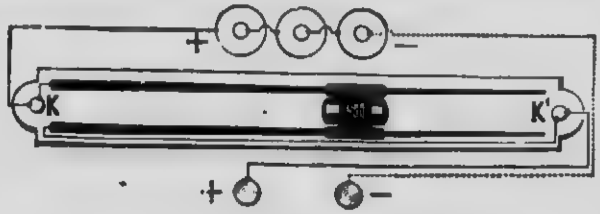


FIG. 47.—PLAN OF GRAPHITE RHEOSTAT.

of the circuit is varied thereby. Graphite rheostats are also made up in other patterns.

Another adjustable resistance apparatus made up in many forms is the "liquid rheostat." It consists of a glass vessel filled with water or some saline solution, through which the current must pass to reach a conductor which is immersed in it. The resistance offered by the liquid varies with the length of

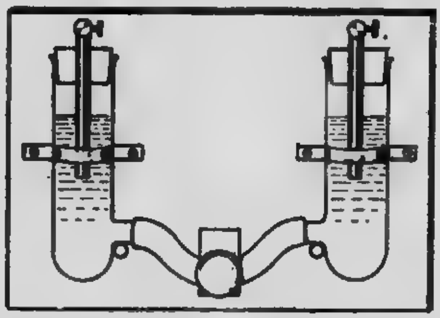


FIG. 48.—LIQUID RESISTANCE OF GUILLOZ.

liquid to be traversed and the nature of the solution, and a wire more or less deeply immersed affords a ready means of varying the resistance in the circuit.

An ingenious form of liquid resistance is made of two glass vessels connected by an indiarubber tube (Fig. 48). The vessels and the tube are fixed to a stand and filled with saline solution. The indiarubber tube is provided with a screw clamp, and when this is tightened the lumen of the tube is gradually obstructed, and in this way the resistance of this part of the circuit can be increased progressively until it becomes practically infinite.

65. **The Management of Batteries.**—The trouble of keeping batteries in order is commonly put forward as an excuse for neglecting electricity in medical practice. As a matter of fact, with a proper modern battery there is no trouble worthy of mention. It is important in buying a battery to choose one which will remain in good order without much attention. On this account acid cells are to be avoided.

Care must always be taken to guard against accidental or intentional short circuiting of any battery. Few batteries will stand short circuiting for many minutes; the dry batteries most used in medical practice are particularly sensitive to it. Short circuiting may easily occur if the electrodes are carelessly thrown down after use, and should happen to lie in metallic contact with each other.

It is bad practice to try to test a battery by connecting the terminals by a direct metallic contact except through a coil of high resistance, for the strength of current may be so great as to damage the galvanometer, and it will probably be too large even with one cell for a galvanometer graduated in milliampères to give readings of it. If no resistance coil be at hand, the plan of putting the electrodes into a little water in a saucer will usually suffice to reduce the current in the circuit to a quantity which can be measured in milliampères. If the battery be not fitted with a galvanometer, one must be attached for this mode of testing. It may be connected to the terminals of the battery, in series with the resistance employed. If this has a value of about 1,000 ohms the current is reduced to a magnitude suitable for measurement with the milliampèremeter; the pointer must then be gradually moved round the studs, the galvanometer being watched carefully. If the battery is in proper order, it will indicate a regular rise in current step by step for every cell added to the circuit. If the galvanometer needle falls to zero as the pointer is passing from one stud to the next, it indicates that the current is broken at that moment, and if a patient were in circuit he would receive an objectionable shock. If the needle falls to zero when the pointer is on a stud, it shows that the connection between that stud and the battery is faulty.

When a battery has been dismounted and put together again, especially if it has many complex connections, there is a danger that the positive pole may have been accidentally connected to the binding-screw marked negative, and *vice versa*. This is

sometimes the case even when the repairs have been done by an instrument-maker. This is an important point, because confusion of the poles may lead to serious mistakes and even to injury to the patient. All risk can be done away with by the use of some method of testing the polarity of the electrodes. It is easy to improvise one. A piece of wet litmus paper on a sheet of glass will show by changes in colour at the electrodes which is the positive and which is the negative pole. The ends of the wires from the battery must be rested on the paper for a few moments, electrolysis will take place, and the litmus will be reddened by the acid liberated at the anode or positive pole, and will turn blue at the kathode or negative pole. Other reagents have been proposed; for example, paper impregnated with a solution of phenolphthaleïn is used as a "pole-finder," and gives a purple-red colour at the kathode or negative pole.

For medical men the use of litmus paper is the most simple means of determining the polarity of wires or terminals, because litmus paper is a reagent which they have always at hand.

66. **Accessory Apparatus—Conducting Wires.**—The conductors or leads by which the current is conveyed from the battery to the patient should be of stranded flexible copper wire insulated with cotton or silk, or they may be enclosed in rubber tubing. The latter is heavier, but protects the wires from moisture and consequent electrolytic corrosion, which is often troublesome when large currents are used, as in ionic medication. It is useful to have the two conductors covered in two different colours, to make it more easy to distinguish them in tracing their attachments to the battery or to the electrodes. A convenient length is four feet and a half or five feet. Suitable cords with ends to fit the battery terminals are sold by the instrument-makers.

It is important to know that the slender and oft-times flimsy wire core of these covered cords may become broken inside the covering, and give trouble if not discovered, the commonest breaking-point being near the ends. A loose contact is particularly troublesome, for the current may then be on one minute and off the next, and so will cause recurrent shocks which are disagreeable and unnecessary. Faulty connections are among the regular accidents tending to throw electrical apparatus apparently out of gear, and although it is not hard to detect the fault by careful examination, yet only too often much difficulty is found, and in consequence the battery is condemned, or the services of

the instrument-maker are called in. It need not be said that this is the wrong way of doing things, for everyone using a battery should make himself familiar with the proper management of it, in order to avoid the expense and annoyance of frequent recourse to the instrument-maker.

As a matter of fact, with moderate care no difficulty need occur from faulty contacts. It is advisable for the sake of neatness to use but one form of binding-screw, as far as possible. There are of course many forms in constant use, and a few minutes may be well spent in inspecting an electrical instrument-maker's stock.

67. **Electrodes.**—The conductors through which the current is applied to the body are called electrodes. The word electrode has also been used to describe the connections by which the current leaves the battery or enters any instrument, and also the wire conductors of a circuit, but in medical usage the word electrode is employed to signify the special terminals which are applied to the patient. They were formerly called rheophores. The variety in nature and shape of the electrodes used in medical practice is great, and it will be useful to describe some of them.

The old-fashioned brass handles and wet sponges should be wholly abandoned, in spite of the fact that instrument-makers still persist in supplying them, and the proper form of electrode to use is a disc or plate of metal covered over with chamois leather, or some other absorbent material.

Care must be exercised to keep the electrodes clean, and on this account metal is a better material for electrodes than carbon, which has been employed. Uncovered metal must not be applied directly to the skin, as it produces painful sensations, or may even cause sores, by electrolytic action upon the surface of the skin. The absorbent coverings must be often renewed, and as far as possible a separate set should be kept for each patient. Lint, absorbent cotton-wool, and even asbestos cloth and blotting-paper, as well as leather, have been used for covering the electrodes.

In some medical applications both the poles of the battery are used equally, and in that case the electrodes at the two poles may be similar, but in others the current is applied to the affected part with one pole, which is then known as the "active electrode," the circuit being completed by the placing of the other electrode, called the "indifferent electrode," on any convenient part of the body; under these circumstances the active

electrode generally requires a handle for its proper manipulation, while the indifferent electrode is most conveniently arranged as a padded metal plate. Zinc plates may be used, but they soon look shabby, and perhaps the best metal of all is silver; for though this soon tarnishes, it is not difficult to polish it, and it seldom forms soluble salts, the usual electrolytic reaction being the formation of insoluble silver chloride, which adheres to the metal. On the back of the plate a binding-screw is affixed for the attachment of the battery wire, and the other side is covered with the absorbent material, which must be moistened with warm salt and water before use.

A good electrode needs a sufficient layer of absorbent material to cover its surface, and this if folded over the edge of the plate tends to make the electrode thick and clumsy; on the other hand, if the edge of the plate is not protected, the skin of the patient may be injured during the course of a long application. After trial of many materials for covering electrodes, I prefer a material known as "carpet felt." It is of good thickness, and when once it has been thoroughly wetted it conducts well. It should be so cut as to extend for half an inch beyond the margin of the metal all round, and if the plate be pierced with holes along its margins the felt can be stitched on very quickly.

For the active electrode metal discs of several sizes are required, and for large currents large electrodes should be used. These will all screw on to the same handle and be interchangeable.

It will generally suffice to have three or four sizes of disc electrodes the smallest of half an inch, or one centimetre in

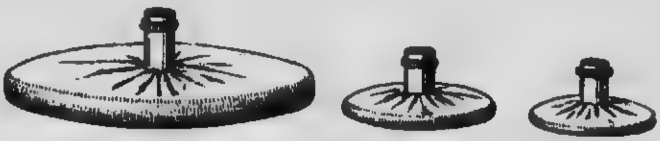


FIG. 49.—ELECTRODES.

diameter, the largest of four inches. A roller electrode is sometimes useful, and occasionally, though very rarely, an electrode in the form of a wire brush is used to produce a brisk and painful cutaneous stimulation. Chamois leather is a good covering material for these disc electrodes, or fine linen or cotton in several layers. The material is sewn on easily, as shown in the figure (Fig. 49).

A good form of disc electrode is one in which the operation of renewing the absorbent covering can be quickly carried out without needle and thread. Its construction is shown in Fig. 50. It consists of two cupped discs of metal, which screw together, and so hold the edges of the wash-leather or cotton material firmly fixed between them.

When the indifferent electrode is slipped between the clothing and the skin, the pressure of the clothes serves to keep it in place, or if the patient is lying down the electrode may be put underneath the shoulders or the hips, or it may be held against the chest or abdomen by the patient himself, or by an assistant. In either case the operator is able to give his whole attention to the

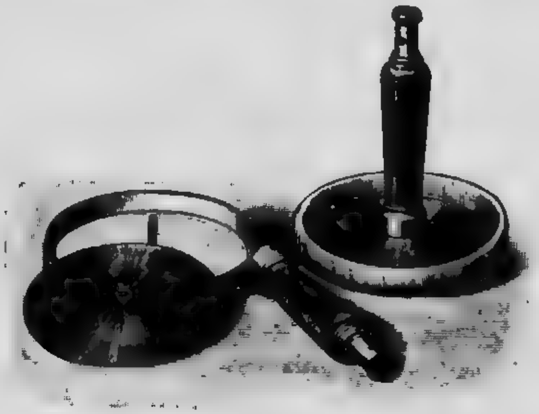


FIG. 50.—DISC ELECTRODES, SHOWING MODE OF AFFIXING THE COVERS.

other or active electrode. Care must be taken to see that the contact of the indifferent electrode with the skin is well maintained, and that no dry clothing lies between. Sometimes it is useful to fasten the electrodes to the surface by a few turns of a bandage, or by a soft garter or belt of some kind. Electrodes to buckle or clasp upon a limb are figured in the catalogues, and are also useful.

A very good electrode can be made of a painter's brush, by soldering a binding-screw to the metal ferrule which contains the bristles. Small flat brushes of this kind make capital electrodes for applying to the face in facial paralysis and other conditions needing face treatment, and larger round brushes are good for applications to the limbs. They do not conduct so well as the

electrodes already described, but when they have had a preliminary soaking in salt solution, they conduct quite well enough. They become discoloured after a time, and therefore should be frequently renewed.

For testing purposes an electrode handle should be provided with a key for closing the circuit (Fig. 51). Electrodes with opening keys are also made, but are less useful. Special forms of electrode for particular purposes will be figured in the sections which deal with the operations in which they are used.

FIG. 51.—ELECTRODE HANDLE FOR TESTING WITH "CLOSING KEY."

68. **Baths as Electrodes.**—It has been mentioned that electrodes with large surfaces of contact are desirable when large currents are to be passed through the body. For this reason vessels containing water or saline solutions are sometimes used as electrodes, and they have the advantage of conveying the current to the surface of the body in a very even manner.

Very large currents can be sent through a patient by the use of baths as electrodes. This use of baths is convenient in applying electricity to the extremities, and it has been further developed into a method of treating the whole of a patient's body at once by immersion in a full-length bath. For these reasons the use of local and general baths for conveying electricity to a patient require describing in some detail. The use of the arm-bath or foot-bath greatly simplifies the process of applying electricity to a patient by doing away with the tedious process of rubbing the electrodes over the affected parts. It is therefore a valuable method of applying electricity, and deserves general adoption. The continuous current, the interrupted, or the sinusoidal current, may be given with equal advantage through the medium of baths.

Any non-conducting vessel of suitable size can easily be arranged to serve the purpose. Oblong troughs are made of a shape and size to take the hands and forearms, and the feet.

A good form of electrode for these arm and foot baths is one made of sheet-metal cut out in one piece in the shape of a

tennis bat, with the handle part bent over so as to hang the electrode from the end of the pan. It is fitted with a binding-screw at the extremity.

The arm-bath is specially suited for cases of paralysis of the muscles of the forearms and hands, as, for example, in the extensor paralysis of lead-poisoning, and in paralysis from injuries to the nerves of the arm and forearm; also in rheumatic and gouty affections and rheumatoid arthritis affecting the elbows, the wrist, or the finger-joints, and in Raynaud's disease, or in chilblains affecting the hands, while the foot-bath is valuable for applications to the feet in the last-mentioned disorders. A consideration of this list will show how often the arm-bath can be of service, particularly in general practice or in the electrical department of a hospital.

When an electric bath is so arranged that one electrode only is immersed, and the whole current passes from it to the patient, it has been called a monopolar bath, to distinguish it from the dipolar bath, which consists of a vessel of water in which both electrodes are placed so that the current passes from one to the other through the water. A limb immersed in such a bath receives part only of the current flowing between the electrodes, the remainder being carried by the water and wasted.

The dipolar bath is useful for the treatment of the forearms and hands, but has its chief application in the full-length electric bath to be described below.

When a monopolar bath is used as an electrode, the other may consist of an indifferent electrode of large size placed upon some part of the body, or it may be used in a second bath, and this is generally the best arrangement.

69. **The Four-cell Bath of Dr. Schnee.**—This is a monopolar bath carried to a high degree of elaboration. It consists of a special chair provided with four baths, one for each limb of the patient who sits in the chair (Fig. 52). The baths are fitted with carbon electrodes connected to the source of current, which can be made to traverse the patient's limbs in any required manner. Thus in cases of paraplegia the two foot-baths could be used, in hemiplegia one arm-bath and one foot-bath, and so on. A switchboard forms part of Dr. Schnee's apparatus, and it is fitted with voltmeter and ammeter, with an adjustable resistance for purposes of regulation, and with a small motor generator by means of which sinusoidal or interrupted current

can be supplied to the baths. There is also a simple arrangement of switches, so that any of the baths can be made either positive or negative at will.

One of these instruments has been in use at St. Bartholomew's Hospital for several years, and has proved to be a valuable appliance for the electrical treatment of many kinds of cases. When used with direct current, 20 milliampères can be comfort-

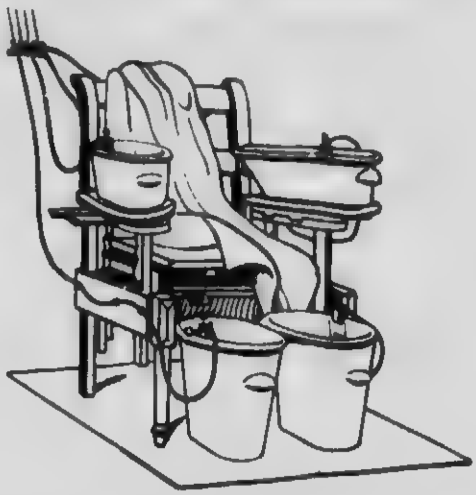


FIG. 52.—THE FOUR-CELL BATH OF DR. SCHNEE.

ably borne from arm to arm, and the electromotive force needed to produce this magnitude of current is about 25 volts.

70. **The Electric Bath.**—The full-length bath, in which the patient is completely immersed, may now be considered. It is used in the treatment of many morbid conditions because it provides a convenient and agreeable way of applying general electrisation to the whole system, a mode of treatment of great value whenever general stimulating and tonic effects are required.

The electric bath is not only the best method of applying general electrisation, but it also has great advantages for local treatment when the area to be treated is an extensive one, as, for instance, in sciatica, in hemiplegia, or in infantile paralysis, where the whole of one or more limbs may require electrical treatment.

The advantages of using a bath of water as a means of conveying electricity to a patient are as follows :

First, the water provides the best of conducting media because

it adapts itself so completely to the surfaces of the body. Secondly, by moistening the skin uniformly and thoroughly, it lowers its resistance and favours the comfortable passage of the current through the skin.

Thirdly, all parts of the body are brought under treatment together, and this simplifies matters both when the body as a whole is to be treated, or when there are a number of separate areas all requiring attention.

Fourthly, because the warm water serves to keep the patient warm and comfortable during the time of the application. We may also include the stimulating action of the hot water upon the skin, for this is an additional therapeutic means that may often be of service in the cases which are being treated by electricity.

The bath itself should be made of porcelain or glazed earthenware, or it may be made of wood. The former is the best, as it is easily kept clean and has a good appearance.

A bath five feet six inches in length is long enough for the great majority of cases. For most female patients a five-foot bath is long enough.

The water in the bath should be agreeably warm, averaging 99° F., but it may be slightly warmer or cooler to suit the wishes of the patient. It is noteworthy that a difference of one or two degrees makes a great difference in the sensations of warmth felt by the patient at these temperatures. On this account a bath thermometer should always be used to ascertain and regulate the temperature. The bath should be so filled with water that when the patient lies in it the whole body and the shoulders may be covered.

Two electrodes consisting of metal plates are fixed at the head and foot of the bath, and they should always be kept clean and bright. These metal plates are provided with binding-screws to which the battery wires are attached (Fig. 53). Copper has a bright appearance, but zinc may also be used. It is of no use to have the electrodes plated with nickel or silver, as is sometimes done for appearance' sake, for the plating quickly leaves the positive pole. The electrode placed at the head of the bath is usually the larger, and may measure eighteen inches by twelve, that at the lower end of the bath being eleven inches by nine. In order to localize the current more or less in any part, a movable paddle (Fig. 54), two or three inches square, connected

by a long flexible wire to the foot-plate, may be used. It may either supplement the foot-plate, or replace it. The water in the bath should be deep enough to cover the plates.

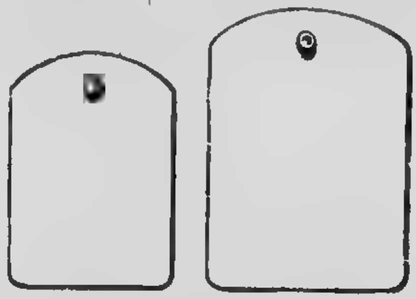


FIG. 53.—ELECTRODES FOR THE BATH.

The shoulders and back of the patient are kept from touching the plate at the head of the bath by a rest made of wood, something like a picture-frame having pieces of webbing stretching

FIG. 54.—PADDLE ELECTRODE.

across (Fig. 55). The light wicker fire-screens which are made to fit on to the backs of chairs are also convenient. Perhaps the

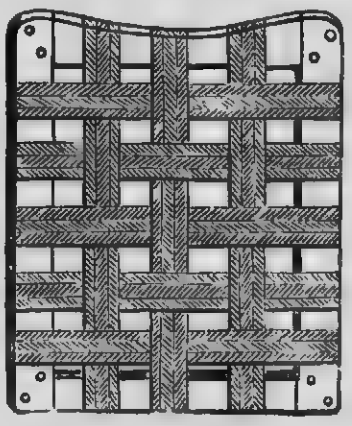


FIG. 55.—BACK REST.

best head-rest is a broad strap of webbing stretched across the bath so as to support the neck. With female patients the bathing-dress gives additional protection to the skin of the back.

The feet may be allowed to touch the electrode at their end of the bath, because the epidermis on the soles is thick enough to take care of itself. If a patient is timid, the feet need not be placed in actual contact with the metal, but they should be kept in close proximity to it. The arms must be extended if they need a share in the treatment, and folded if the current through them is to be kept small. A part only of the total current in circuit traverses the body, the remainder passing through the water in which it is immersed. The water in the bath offers a broad conducting medium with a large transverse sectional area, several times larger than the patient, and therefore a considerable part of the current traverses the water and is altogether lost to the patient.

An electric bath was installed at St. Bartholomew's by the late Dr. Steavenson in 1882, and was for many years the only electric bath at a London hospital. Recently, one or two other hospitals have recognised their advantages and have taken them into use. The bath method of applying electricity has further been extended by the introduction of arm-baths and foot-baths, as well as the large general bath; so that there are now at St. Bartholomew's Hospital five of these small baths in regular use, to the great advantage of many patients, and with the effect of greatly simplifying the process of treatment; better results are now obtained in many conditions of disease by bath methods than was formerly the case.

The resistance in an electric bath will vary with its length, with the depth to which it is filled, and with the temperature of the water.

Dr. Hedley* has contributed largely to our knowledge of the physics of the electric bath, and his book should be studied by all those who are interested in the subject.

A porcelain bath five feet six inches long has a resistance of about 110 ohms, when filled with water at 100° F. to a depth of fifteen or sixteen inches.

A question of interest with the electric bath is the following:— How much of the total current passes through the patient, and how much is conveyed by the water? The answer will depend upon the dimensions of the bath, and also on the quantity of water in the bath; the problem is best attacked by regarding

* "Hydro-Electric Methods in Medicine." London: H. K. Lewis, 1896. Second Edition.

the condition as one of a divided or branched circuit; the water being one, and the patient the other of two conductors; the proportion of current traversing each will depend upon their relative resistances. But the thicker parts (trunk) of the patient will convey more than the average, and the thinner parts (limbs) less, so that one cannot say that the patient carries such and such a fraction of the total.

M. Meylan* measured the resistance of a bath, first with a patient immersed; secondly, with the patient removed, the water as before; and thirdly, with the patient removed, but with water added to bring the level up to that which it had when the patient was in it.

The measurements were as follows:

A. Water and patient ..	..	136 ohms resistance.
B. Water only ..	.. ..	151 „ „
C. Water, with water added ..		130 „ „

By calculating out these figures he arrives at 1,360 ohms as the patient's resistance, and 1,033 ohms as that of the equivalent bulk of water added in experiment C. The resistance of the patient was rather greater than that of his own volume of water spread out in a layer over the area of the bath. The cubic measurement of an average-sized man is three cubic feet, or about eighteen and a half gallons.

If we compare the resistance of the water only, 151 ohms, with that of the patient, 1,360 ohms, we find that under the conditions of the particular bath the patient's body would be conveying about one-tenth of the current.

As the current which traverses the water does not affect the patient, and therefore may be considered as wasted, it follows that for economy of current the amount of water used in the bath should be no more than enough to cover the patient comfortably. On the other hand, a large volume of water retains its heat better for the time required for the bath, and should be preferred on that account, the waste of current being a matter of minor importance.

If salt or acid is added to the bath, the water becomes a better conductor than before, and the patient's share of the total current passing will be reduced. It is therefore improper to make such additions to the water. The duration of a bath

* *Revue Internationale d'Électrothérapie*, vol. v., p. 113 (November, 1894).

should be from ten to fifteen minutes. The baths may be given on consecutive or on alternate days.

71. **The Electric Douche Bath.**—A douche of water may also be used to convey an electric current to a patient in a bath.

In the *Revue Internationale d'Électrothérapie* for June, 1894. Dr. Guyénot, of Aix-les-Bains, has described a method of applying electricity by means of douches. The current is led to and from the patient by two streams of water, the conductors being connected to the metal nozzles through which the water flows, and he insists upon the ease with which the jets of water can be made to carry the current to the whole surface of the body, or to any part of it, so as to give the effect of a general or of a localized electrization. The article gives careful working details of the modes of applying either the battery current or the induction-coil current, and the account is well worthy of attention.

72. **Rhythmic Interrupters.**—In medical treatment it is sometimes useful to interrupt or to vary the current rhythmically, and several mechanical devices have been invented for turning a current off and on at regular intervals. The advantage of using regularly varying currents is gradually becoming recognised, and such currents are specially adapted for cases in which electricity is employed to stimulate the nutrition, either of the whole body, or of any part of it. In conjunction with electric baths of all kinds the rhythmic interrupter is almost a necessity.

By the term "rhythmic interrupter" is meant a mechanical device for turning currents on and off in a regular periodic manner, and there are two main varieties of rhythmic interrupter, giving different effects, and both are valuable in medical treatment. In the older type the current is simply switched on and off at a uniform rate, the change from "on" to "off" being abrupt; while in the newer type there is a gradual growth of current from zero to its maximum, followed by a similar gradual decrease to zero again. This is the most generally useful type of rhythmic interrupter for medical treatment, but the first type requires some brief notice, too. For sudden turning on and off of current a simple metronome, with wires dipping into mercury cups, fills the requirements completely. This apparatus is well known in physiological work, and is known as Kronecker's (more correctly Bowditch's) metronome (Fig. 56). This type of rhythmic interrupter, in one form or another, has been in use since the very early days of electro-therapeutics. To connect

it up one of the wires from the battery is taken to the central mercury cup, whence the current passes along the moving arm to one of the other cups and from there passes by another wire to the patient. Binding-screws are provided for these connections. The third cup is not used. This form of interrupter is most useful in the electrical testing of nerve and muscle, and will be referred to again under that subject.

FIG. 56.—METRONOME INTERRUPTER.

The second type of rhythmic interrupter—namely, that in which the current is made to rise slowly from zero to a maximum, and again to fall slowly back to zero—is the type which is more particularly valuable for many forms of electrical treatment. To effect this gradual change of strength of the current is a matter of difficulty, but this is overcome in the apparatus about to be described (Fig. 57). It consists of a train of clockwork which communicates an up-and-down movement to the end of a horizontal arm, and this arm carries at its end a vertical platinum wire, which in its excursions dips down into a cup of water, penetrates nearly to the bottom of the cup, and then rises again until the extremity of the wire almost emerges from the surface of the water. The current passes from the wire to the cup through the water, and the resistance of this part of the circuit alters with the depth of immersion of the wire, and consequently the current passing through the circuit varies proportionately, and continues to vary so long as the movement up and down of the platinum wire continues. The greater the range of resistance in the cup,

the greater is the range of the current through the patient, who is connected up in the circuit in such a way that the current passes first through the interrupter and then onwards through the patient. To increase the range of resistance in the cup a small glass funnel is inverted in it, and the platinum wire moves up and down in this inverted funnel. When the point of the wire is at the top of its excursion upwards, its point, though still immersed, is in the narrowest part of the stem of the inverted funnel, and the resistance then is high and the current small. On the other hand, when the wire has descended to its lowest point it lies close to the metal of the cup, and is surrounded by a wider area of fluid, and the resistance is low, and the current,

FIG. 57.—RHYTHMIC INTERRUPTER, OPERATED BY CLOCKWORK.

therefore, is large. It is easy, with this little contrivance, to arrange a current varying rhythmically between 1 and 10 milliampères through a patient, and this gives as wide a range as is required. The rate or periodicity should be of about one complete cycle in four seconds, or fifteen per minute.

As the amplitude of the range of current through the patient depends upon the amount of the resistance which can be interpolated by the excursion of the moving wire, it follows that the liquid in the cup should have a high resistance and not a low one. To add salt to the water decreases the range of current very much. Tap water is the proper fluid to make use of in the cup. In order that it may be easy to adjust the platinum wire it is made to slide through a vertical hole at the end of the horizontal arm, and can be clamped when in position, the best being when

it can almost touch the bottom of the cup at the end of its downward range, and almost emerges from the surface of the water at its topmost position. This mode of fixing the platinum wire also permits of its easy withdrawal for cleaning, and the metal cup is also free of all fixed connections for the same reason. The current enters the base of the cup from a metal saucer on which the cup stands, the cup and the saucer being made of a nickel crucible and its lid, which are inexpensive and eminently suitable.

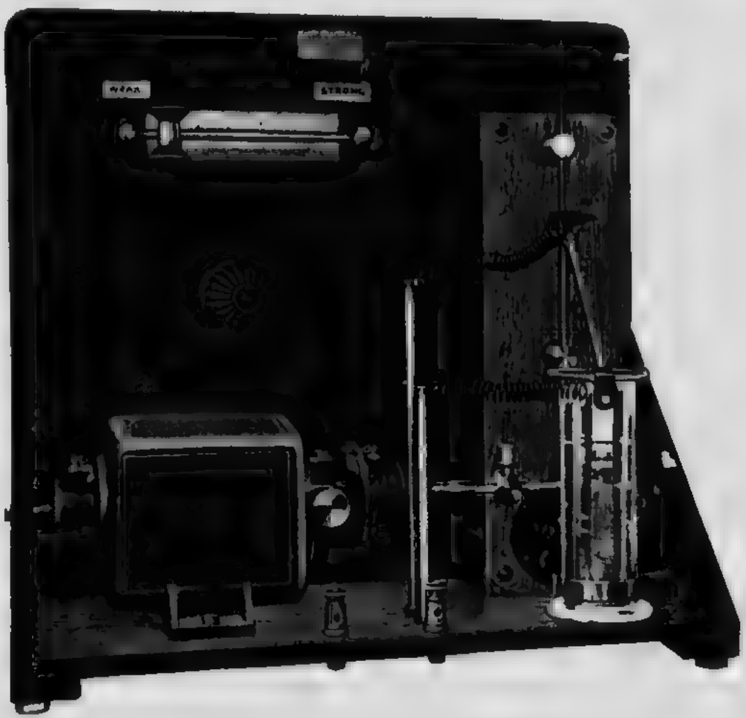


FIG. 58.—RHYTHMIC INTERRUPTER, MOTOR-DRIVEN.*

I have used an apparatus of this kind for a number of years. With this device either continuous or interrupted or alternating current may be rhythmically regulated

During rhythmical electric stimulation the tissues stimulated are given recurrent intervals of repose in the course of the treatment, and time is thus given for renewal of blood-supply, and fatigue is prevented. A sustained stimulation without any

* For these two drawings I am indebted to the courtesy of the proprietors of the *Lancet*, the original description having appeared in that journal for November 13, 1909.

intervals tends to induce fatigue quickly, particularly in weak or paralyzed muscles, and it is probable that harm may be done by electrical applications which set up a sustained tetanization in such muscles. If experimental proof were needed of the value of rhythmic stimulation, it is to be found in the experiments of Débédat* upon the muscles of young rabbits. He showed that rhythmic stimulation of the muscles of one hind-limb for ten minutes daily caused, after twenty days, an increase of 40 per cent. above the weight of the corresponding untreated limb. The current used was that of an induction coil. With continuous current also applied rhythmically the increase was

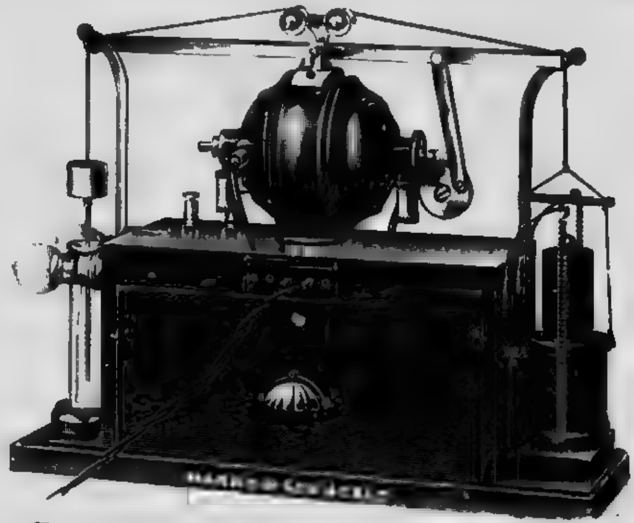


FIG. 59.—DR. HAMPSON'S RHYTHMIC INTERRUPTER.

only 18 per cent. When similar applications, but with no rhythmic intervals, were used, the gain in weight was *nil* both for interrupted and continuous currents. Bordier,† working with human subjects, has obtained similar proofs of the good effect of rhythmic currents, for he reports an increase in girth of ½ inch in the arm after two months of rhythmic stimulation.

Another excellent motor-driven rhythmic interrupter is shown in Fig. 59. It is designed by Dr. Hampson, of the Queen's Hospital for Children, and is described in the *Archives of the Roentgen Ray*, October, 1910, p. 182. In the *Lancet* ‡ recently

* *Archives d'Electricité Médicale*, February and March, 1894.
† *Ibid.*, 1902, p. 331 (with illustration).
‡ *Lancet*, January 8, 1910 (with illustration).

Dr. Norman Aldridge has described a very simple form of rhythmic interrupter, in which the variations of resistance are produced by the filling and emptying of a test-tube in which two conductors are arranged. The periodical filling and emptying of the tube is brought about by means of a flow from a tap to fill the vessel, which then empties itself automatically by a syphon, and the author of the paper says that this can easily be arranged to work automatically and with perfect regularity. He has employed this device with arm baths, and finds it quite satisfactory.

Mr. Schall has designed a very good form of rhythmic interrupter in connection with the pantostat which is described in § 92. The interrupter is worked by the motor which forms part of that apparatus, and this renders unnecessary the use of a separate motor for operating the interrupter.

CHAPTER III

CAUTERY AND LIGHTING INSTRUMENTS—THE ELECTRO-MAGNET

The galvano-cautery—Batteries for cautery purposes—Accumulators—Wires and leads—Lamps—Batteries for lamps—The cystoscope—Endoscopes—The antrum lamp—The electro-magnet—Ozone.

73. **Indirect Applications of Electrical Currents.**—The preceding chapter contained an account of the apparatus commonly used for the direct application of electrical currents to the body. The present one considers certain instruments in which electricity is indirectly employed, and which are often valuable in medical practice. These are the galvanic cautery, the various forms of exploring lamp, and the electro-magnet as used for the removal of splinters of iron and steel from the tissues, particularly from those of the eye. A few notes on the medical applications of ozone are also added, although this agent has not yet been employed very largely for medical purposes.

74. **The Galvanic Cautery.**—The forms of galvano-cautery in common use are numerous, but their plan of construction depends upon one general principle. They consist of small loops of

COXETER & SON. LONDON.

FIG. 60.—CAUTERY POINTS.

platinum wire mounted on straight or curved copper supports, which are insulated from each other by varnish and by turns of waxed thread, which also serve to hold them together to form a convenient stem (Fig. 60). These are made in various lengths

to suit different purposes, and they fit into sockets in a handle provided with binding-screws or other forms of connector, and with a key for opening and closing the circuit. The platinum loops, having a relatively high resistance, become heated by the passage of the current (§ 22). Fig. 61 shows a usual form of holder.

For small-sized burners a very good handle is made in the shape of a metal pencil-case (Fig. 62). Connection is made through a twin wire ending in a concentric plug which fits a

Fig. 61.—Schech's Cautery Holder.

socket at the end of the handle, and the closing switch is a ring of metal sliding over a piece of ivory.

The current which heats the platinum points heats the rest of the circuit as well, in a less degree; the current, therefore, should only be left on when the cautery is in actual use.

Besides the simple loops of platinum wire there are others intended to serve as cutting instruments, which are made by hammering the platinum flat or by bending it in various ways.

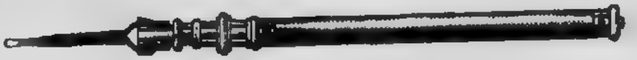


Fig. 62.—Cautery Handle.

Where a large incandescent surface is required, a loop or spiral of platinum supported in grooves on a porcelain mount is used, the porcelain becoming heated to redness as well as the platinum. Different thicknesses of platinum wire are used, and accordingly the current required to raise the burners to a red heat varies greatly in different cauteries.

Sometimes a long loop of wire is used as an ecraseur, being adapted cold to the part to be removed, and then heated, a screw on the handle being used for gradually tightening the wire

loop when hot. As the wire loop is shortened the regulating resistance must be progressively adjusted, or the wire will become overheated. Steel wire is sometimes used for these loops on account of its cheapness, but platinum is the best. It is as well to mention that the temperature of a cautery must not be allowed to rise above dull redness. At a white heat the cauterizing action is so rapid that searing of the surface does not take place, and hæmorrhage may follow as profusely as after division of the tissues by a knife. Many forms of cautery and mount will be found illustrated in the instrument-makers' catalogues. The resistance of the cauteries just described may vary from 0·025 to 0·04 ohm.

The current required to bring the platinum loops to redness varies between five or six ampères for the smallest to upwards of twenty for the larger ones.

Still larger currents are required for a few cauteries, which have been constructed for special purposes.

75. **Cautery Batteries.**—The batteries of small cells which are used in medical treatment are of no use for cautery currents. They are designed for high electromotive forces and small currents, while for cautery purposes large currents and low electromotive forces are required. Chromic acid cells can be used for cautery purposes, because when of good size they are able to yield large currents for brief periods. Fig. 63 shows a special form of this battery with four cells, which is arranged to permit of use as a two-cell battery with pairs of cells in parallel (§ 29) for cautery purposes, or with four cells in series for exploring lamps, which need a rather higher electromotive force than is required for cauteries. In places where storage cells cannot be used this form of cell may be had recourse to, but wherever the electric mains are available or an accumulator can be kept in order these will be used in preference. The use of the electric lighting mains for cauteries and lamps and for accumulator charging will be considered in the next chapter.

A small four-celled accumulator can be fitted with a switch for rearranging the cells in two pairs in parallel. It can then be used either as a two-cell accumulator (four volts) of double cells for cautery purposes, or as a four-celled one for lamps (eight volts). Fig. 64 shows such an apparatus, which is constructed for surgical purposes. It weighs fifteen pounds, and is provided with two resistances, fixed upon the lid of the box, one for lamp and one

for cautery use. The connections are so arranged that the lamp resistance is in series with the lamp terminals, and the cautery resistance with the cautery terminals. The cells must not be left in parallel when the battery is not in use.

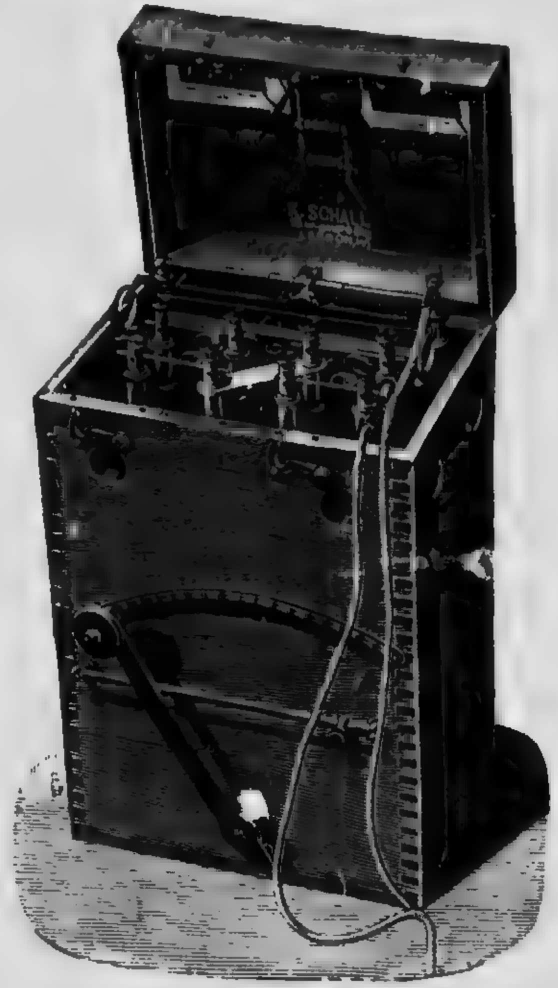


FIG. 63.—CHROMIC ACID BATTERY FOR ELECTRIC LAMPS AND GALVANO-CAUTERY.

76. **Conductors.**—It is important to use thick copper wire conductors in cautery work because the resistance of the whole circuit being very low, that of the conductors becomes an important fraction of it, and may determine whether the cautery will be properly heated or not.

It may be useful to give an example here of the calculations to be made in arranging the apparatus for heating a cautery. Suppose that a cautery having a resistance of 0·04 ohm and requiring a current of 20 ampères is to be heated, and that the battery power available consists of two accumulator cells in series, each with an electromotive force of two volts, the internal resistance of each cell being 0·01 ohm.

To obtain a current of twenty ampères from four volts the total resistance in circuit may amount to 0·2 ohm. If proper leads are used, their resistance will be 0·0014 ohm per metre. We will suppose each wire to be 1·5 metres in length, their

FIG. 64.—ACCUMULATOR FOR LAMPS AND CAUTERIES.

total resistance will then be 0·0042 ohm. The necessary resistance in circuit in this case (resistance of battery, of leads, and of cautery) therefore amount to $0{\cdot}02 + 0{\cdot}0042 + 0{\cdot}04 = 0{\cdot}0642$, or say 0·065 ohm. This leaves a margin for faulty contacts and for rheostat of 0·135 ohm, and the cautery would be adequately and easily heated.

But now suppose that the leads are of a size having a resistance of 0·04 ohm per metre. This will give a total resistance in circuit of $0{\cdot}02 + 0{\cdot}12 + 0{\cdot}04 = 0{\cdot}18$ ohm, leaving a bare margin of 0·02 ohm for faulty contacts. This would be insufficient, as there are several points of contact, and a small degree of oxida-

tion or tarnishing at any one of them would prevent the cautery from heating, add to which there would in all probability be a considerable amount of heating in the leads, which would certainly increase their resistance, and might injure their insulation. These examples show the importance of using conducting wires with plenty of copper in them, and of keeping all contacts and binding-screws scrupulously clean and bright. A regulating resistance must always be included in the circuit when a cautery is to be heated, for if this precaution is neglected there will be much trouble from overheating and fusing of the platinum loops.

An open helix of thick German silver wire with a sliding contact piece is generally used for a resistance, and one made after the pattern shown in Fig. 64 may be used. As will be seen from the calculations in the preceding paragraphs, its resistance in ohms should be quite small.

77. **Lamp Instruments for Diagnosis.** — Small incandescent lamps have been adapted to laryngoscopes, ophthalmoscopes,

Fig. 65.—Laryngoscope with Electric Lamp.

otoscopes, vaginal specula and other instruments (Figs. 65 and 66). They are not used very universally, because in many cases other sources of illumination are sufficient.

Fig. 66.—Ophthalmoscope with Electric Lamp.

On the other hand, certain new exploring instruments have come into use whose value depends entirely upon the advantages resulting from the use of the electric illumination. The cystoscope, the gastroscope, and the antrum lamp are examples of this form of lamp instrument. The small lamps used in these instruments of diagnosis are of one or two candle power, and vary a good deal in their resistance (5 to 20 ohms), and therefore the electromotive force required to bring them to incandescence

varies also. If the filament is slender, or if it is long, their resistance is high; if it is short or thick, their resistance is less high. A long slender filament may require ten volts or more to light it properly, while a shorter one may glow with four volts.

The rate of consumption of energy by incandescent lamps with carbon filaments is about four watts (§ 25) per candle. Thus if a ten-volt lamp absorbs 0·4 ampère, a six-volt lamp would require 0·7 ampère to give the same light. In the modern metal filament lamps the consumption of energy per candle-power is much less, being only one watt per candle-power in some of them, and they are therefore much superior to the old carbon filament lamps, requiring less current, and taxing the endurance of the battery far less. When the current is supplied from a portable battery, it is very advantageous to use metallic filament lamps for the sake of the saving in current.

Among primary batteries useful for lighting small lamps the chromic acid cell may be used if no means of recharging accumulators are available. Dry cells are more convenient, but do not last long if used much, though they may be trusted for a fair number of short examinations. It should be borne in mind that dry cells gradually fail as they get old, whether they be used or not. From three to six months may be taken as the duration of usefulness of a dry cell. A Leclanché battery also answers well for lamps if portability is not required.

If accumulators are used, small ones may be had for the sake of portability. Small accumulator batteries for lamps are put up by several electrical instrument-makers. If the small accumulators can be recharged at home from the mains without trouble they are extremely convenient, but this convenience is lost if they have to be sent away every time to be recharged.

The introduction of electric ignition for motor-cars has done much to improve the manufacture of small accumulators and to familiarize medical men with their management. The small two-celled accumulators used in motor-car work may be employed for surgical exploring lamps, and two of these batteries joined in series give a pressure of eight volts. For galvano-cauteries these accumulators are rather small, but they may be used at a pinch for the purpose, and two batteries should then be connected in parallel, and a suitable resistance (§ 64) must then be connected in the circuit.

As the different forms of small lamp vary a good deal in their

resistance a regulating resistance in the circuit is necessary to compensate for these variations, as without it some lamps would be overheated and would quickly be destroyed. Suitable resistances are supplied with many of the types of portable accumulator now in the market. The resistance required for regulating the lamps need not be more than about six or eight ohms. As the current to be carried is only about half an ampère in a well-made lamp the resistance is easily made of a few turns of fine German silver wire. Resistances are equally important for cauteries, but there they have to carry large currents, and must be made of thick wire ; however, their total resistance need not be so great, for a variable resistance of half an ohm is sufficient to modify very greatly the current in a cautery circuit.

Electric lamps are made in a variety of forms with bull's-eye lenses or reflectors for medical use. They may be had on standards, affixed to wall-brackets, or as hand-lamps, and many patterns will be found illustrated in the instrument-makers' catalogues. The Nernst* lamp, combined with frosted or opal glass, gives a bright and uniform illumination, which makes it valuable for some purposes.

FIG. 67.—EXPLORING LAMP.

A convenient form of exploring-lamp is shown in Fig. 67. It is designed in such a way as to be kept clean and aseptic without any difficulty. The glass enclosing tube may be left in the antiseptic solution until required for use. The attachment to the leads is by a double socket fitting, one wire making contact with the periphery of the tube which carries the lamp, and the other with an insulated lead which passes down the centre. The glass tube prevents any burning of the tissues with which it might come in contact. The stem passes through an indiarubber cork.

A head-lamp is useful in many surgical operations. Its present form and arrangement is shown in Fig. 68. It was originally designed by Trouvé, and has been modified by subsequent experimenters.

* The Nernst lamp has a short rod of the oxides of some of the rare earth group of metals in place of a carbon filament, and glows with a whiter and more brilliant light

One interesting form of lamp-instrument has a rod of glass along which the light of a lamp is conveyed by a series of internal reflections. It is quite cool, and may be used for purposes of exploration (see Fig. 69).

FIG. 68.—TROUVÉ'S HEAD LAMP.

78. **The Cystoscope.**—This is an instrument for examining the interior of the bladder, and is one of the most important of all the electric-lamp instruments.

FIG. 69.—GLASS ROD LAMP.

It consists of a beaked sound containing a telescope with which the wall of the bladder is viewed through a reflecting prism of rock-crystal. A lamp protected by a metal cap forms the beak of the instrument, and throws its light upon that part of the bladder-wall which is in the field of view of the telescope. By rotating the instrument the different parts of the mucous membrane can be brought into view, and the direction of the vision is indicated by a small knob fixed upon the eyepiece of the instrument.

Fig. 70 shows the simple cystoscope in its modern form, but of late years there have been many additions to it. Thus it can be modified so that the optical part may be removed, leaving the outer tube in place for washing out the bladder, while in another

form one or two catheters can be passed down the instrument for the same purpose, or for catheterizing the ureter. There are also forms of cystoscope which enable two persons to view the bladder at the same time, and this is very useful for purposes of demonstration, and finally Professor Nitze has devised a cystoscope with photographic attachment.

FIG. 70.—CYSTOSCOPE, SHOWING DETAILS OF LAMP AND MODE OF ATTACHMENT OF CONDUCTORS.

The bladder must contain six or eight ounces of fluid, and if this is even slightly turbid the view is much obscured. A very little blood is quite sufficient to interfere with proper vision, and if any be present it is quite useless to try and force matters by over-running the lamp in order to produce more light. The little lamps in cystoscopes are often grievously ill-treated in this way, but the difficulties in using the instrument are almost always due to turbidity in the fluid. When this is quite clear, the beauty and transparency of the resulting picture is most striking.

If the beak of the cystoscope becomes buried in the loose folds of the bladder wall, there will be no light, and in that case the mucous membrane may be burned. For although the heat of the lamp is unimportant when it is surrounded by a volume of water, when it lies close against the mucous membrane there is no proper circulation of fluid round it, and it grows hot and will burn if held long in one place. The dummy bladder (Fig. 71) is useful for practice at the beginning. For a full account of the instrument and the mode of using it Mr. Hurry Fenwick's admirable "Handbook of Clinical Electric-Light Cystoscopy"* should be consulted. It contains a complete account of the whole subject of the cystoscope and of its use in the surgery of the bladder. The student may also consult a valuable paper in *The Practitioner* for July, 1905, by Mr. David Newman on "The Teaching of Cystoscopy." This paper, like Mr. Fenwick's handbook, con-

* J. and A. Churchill, London, 1904.

tains many illustrations of cystoscopic appearances in morbid conditions.

79. **Electric Endoscopes.**—Other exploring instruments of value are the various forms of endoscope, in which a lamp con-

FIG. 71.—CYSTOSCOPE AND DUMMY BLADDER.

tained in the handle of the instrument projects a beam of light through a prism or upon a mirror inclined at an angle of 45 degrees, which deflect it along the axis of a tube which can be

FIG. 72.—SIMPLE FORM OF INFLATING URETHROSCOPE.

introduced into the channel or passage to be examined. Many forms of endoscope have been devised, and one of them is shown in Fig. 72. Fig. 73 shows another type of instrument, in which a small lamp is carried near the extremity of a speculum. The

sigmoidoscope is an instrument of this type, for the examination of the rectum and pelvic colon.*

There are also instruments for examining the trachea and bronchi, and the œsophagus and stomach. None of these

FIG. 73.—VAGINAL ENDOSCOPE.

instruments present any difficulties from the electrical point of view, but in them, as in all other surgical lamp instruments, the temptation to overrun the lamps should be resisted. For descriptions of these instruments and how to use them the special books and papers concerning them should be consulted.†

80. **Transillumination.**—The ease with which small electrical lamps can be brought into close contact with the tissues without fear of burns has led to the invention of new methods of examination which may be conveniently grouped together under the name of transillumination. These methods depend upon the translucency of the tissues; thus a lamp placed in the mouth will light up the tissues of the nose so that these appear luminous, and the nasal passages may thus be viewed in a darkened room by the light transmitted.

Czermak in 1858 discovered that the larynx could be examined when illuminated from without by a beam of light concentrated upon the external surface of the neck at the level of the thyroid cartilage, and Voltolini in 1888 found that the bones of the face could be illuminated by the light of an electric lamp held in the mouth.

The exploration of the antrum of Highmore by means of a

* "The Sigmoidoscope," by P. Lockhart Mummery (London: Baillière, Tindall and Cox, 1906).

† M. H. Tilley, "Direct Examination of the Larynx, Trachea, and Œsophagus, by Brüning's Instrument," *Lancet*, November 7, 1908.

T. J. Faulder, "Direct Œsophagoscopy," *British Medical Journal*, August 27, 1910.

W. Hill, "On Gastroscopy" (London: John Bale, 1912). This contains a short bibliography of the subject.

lamp placed in the mouth has excited a considerable amount of interest since the publication by Heryng of his paper on the subject in 1889.

81. **The Antrum Lamp.**—This instrument (Fig. 74) consists of a small lamp carried on a curved handle, and having a plate of ebonite to protect the tongue. Dr. Brown Kelly * recommends the use of a series of cylindrical caps which are slipped over the lamp, and have openings at the end or side to suit the different applications of the instrument. To use the antrum lamp the patient must be brought into a darkened room, the lamp is introduced into his mouth, and the lips are closed over its stem; when the current is then turned on, the face becomes lighted up by a red glow. If one antrum contains pus, a dark shadow is seen on the corresponding side, which is most percep-

FIG. 74.—ANTRUM LAMP WITH VARIOUS LAMP CAPS.

tible just below the eye. The lamp used should have an illuminating power of three or four candles. For details of the use of the antrum lamp in practice see one or other of Dr. Kelly's papers.

82. **The Gastro-diaphane.**—This is a transillumination contrivance for lighting up the stomach from within in order to enable an opinion to be formed of its size and position when viewed from without. It consists of a stomach-tube of soft rubber carrying a pair of wires, and at its end there is a small electric lamp which is protected by an outer cap of glass. Usually the instrument is fitted with a channel for conveying

* "Transillumination of the Antrum of Highmore," *British Medical Journal*, March 25, 1905, with special coloured plate.

"Contributions to the Pathology and Diagnosis of Certain Affections of the Antrum of Highmore" (Glasgow: A. Macdougall, 1905).

water into the stomach. To use the apparatus the lamp is passed into the stomach; the patient must be in darkness; when the light is then turned on a luminous glow is seen in the region of the stomach, and the appearance of this in normal individuals should be known in order to judge of alterations due to disease. The stomach should contain eight ounces of water, but no food. Herschell* states that the illuminated area of the stomach may be obscured by liver, by intestine containing fæces, or by tumours, and that the lower part only of a normal stomach is translucent, but if the whole stomach is illuminated gastroptosis is most likely present, and in this case the illuminated area does not move with respiration. In dilatation of the stomach the upper border of the stomach is not seen, and

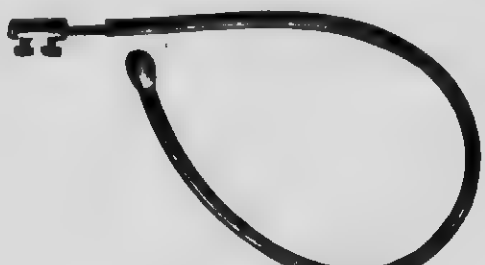


FIG. 75.—THE GASTRO-DIAPHANE.

respiratory movements are present. This instrument has been superseded by the X-ray examination of the stomach.

83. **The Electro-magnet.**—In certain cases this instrument is very valuable for the removal of fragments of iron or steel from the various parts of the body, and most especially from the eye. If the particle of iron be very small, or if it be fixed at all firmly in the tissues, a magnet is not likely to remove it. But if the piece of metal be larger, and if it be lying loose, as, for example, in the interior of the eye, it may be withdrawn most successfully by a magnet. Hand magnets are most often useful, and can be wound either to suit accumulators or for use on direct current electric light mains. They are cylindrical in shape and fitted with pole pieces both straight and curved, and can be brought up to the eye as required.

Of late years giant electro-magnets on stands have been

* "A Manual of Intragastric Technique" (London: H. J. Glaisher, 1903).

employed by Professor Haab and others. These instruments are unwieldy, and difficulties are sometimes experienced in manipulating them, but they are popular among ophthalmic

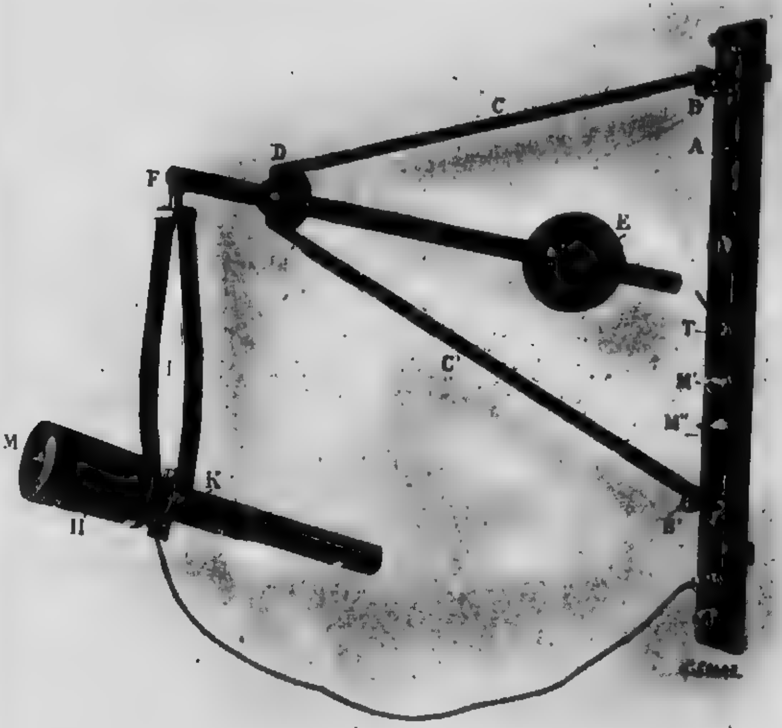


FIG. 76.—GAIFFE'S GIANT ELECTRO-MAGNET.

A, wall plate; B, C, D, hinged supports carrying the magnet ,H, M, and counterpoise, E, in a bronze loop, I, with hinges, F, K; M, pole piece; M', M", T, spare pole pieces.

surgeons at the present day. Figs. 76 and 77 show two forms of giant magnet. In a recent number of *The Ophthalmoscope** the arguments in favour of hand-magnets and of giant magnets

* February 1, 1905.

are discussed in three valuable papers by Professor J. Hirschberg, Professor O. Haab, and Professor S. Snell. The former appears to prefer the hand-magnet, though he speaks of the giant as having considerably increased the number of curable cases. Professor Simeon Snell, whose special acquaintance with the

FIG. 77.—HAAB'S ELECTRO-MAGNET, WITH FOOT-SWITCH.

use of electro-magnets dates back to the year 1881, points out that the results from the use of Haab's magnet have by no means overwhelmed those of the hand-magnet, and gives it as his opinion that "the value of the hand-magnet should always be set forth whatever be the views of those employing the large

magnet." The student should consult the journal just quoted for further information on the subject.

Although the action of huge electro-magnets in attracting large pieces of iron from a distance may impress the casual observer, it must be borne in mind that there is a limit to the number of magnetic lines which can be crowded into a mass of iron, and that any increase of current beyond that by which the iron core is magnetically saturated is of small advantage. Thus it is probable that any electro-magnet carrying a sufficient current to produce magnetic saturation will be equally effective in attracting small particles of iron, and that for the small fragments which occur in the globe of the eye there can be no advantage in using very large instruments, because the attractive effect is due to the magnetic field at the pole-tip which is presented to the eye, and depends also to a very great extent upon the size of the particle of iron or steel to be acted upon. It is the small particles rather than the large ones which are so difficult to extract.

84. **Ozone.**—This unstable oxygen molecule (O_3) has been proposed for use in therapeutics by many writers, but hitherto no striking advantages have been proved to follow its use. Indeed, it has been shown to be noxious when present in the air in any but the smallest proportions. The presence of less than a milligramme of ozone per litre was found by Dr. Bordier to prove fatal to a guinea-pig in half an hour, and the results found post mortem indicated that the ozone acted as a violent irritant to the respiratory tract.

Ozone in moderate quantities is found in the neighbourhood of all high potential electrical apparatus when in action, being produced by the effect of the brush discharges upon the oxygen of the air. Frequently some nitric oxides are produced at the same time, and these doubtless increase the irritant action of the ozone. Nevertheless ozone has been tried in various affections of the respiratory tract, as, for instance, in whooping-cough and in phthisis, and it has been strongly recommended by French writers for the first of these disorders. It is also said to increase the percentage of hæmoglobin in anæmic persons.

Ozone is coming into use for the disinfection of crowded rooms, as it possesses very marked oxidizing properties, and adds nothing to the atmosphere except oxygen. Many forms of apparatus for producing ozone have been devised.

In the best forms of apparatus air or oxygen is blown quickly through a channel between two surfaces of glass whose other surfaces are covered with a layer of tinfoil, and are connected to the terminals of an induction coil or a high potential transformer. A convenient form for the apparatus to take is that of two concentric cylinders, the one fitting inside the other with an air-space between. When the apparatus is in action, a violet glow is seen in the air-space, and the air blown through it comes out with the characteristic smell of ozone. For purposes of inhalation it has been advised to use oxygen rather than air for the source of the ozone, in order to avoid the production of the

FIG. 78.—OZONE APPARATUS.

oxides of nitrogen. The oxygen can be obtained from a cylinder of the compressed gas, and this obviates the need of any bellows for maintaining the flow.

A compact ozone-producing apparatus has lately been introduced by the Ozonair Company* for the purification of the air of rooms, as well as for numerous industrial processes. This apparatus consists of an ozonizer, with an induction coil or high-potential transformer, and an electric fan, combined in a convenient form. It produces a continuous flow of ozonized air, and there is said to be a total absence of nitrous vapours. It is made to work upon any electric light supply, and the consump-

* 96, Victoria Street, Westminster.

tion of current is trifling. The apparatus is made in many patterns, both portable and otherwise, and in several sizes to suit the cubic space of the room to be ozonized. It can also be worked from accumulators, if no electric light main is available. One of their patterns is figured here (Fig. 78). In view of the results which have been obtained in the treatment of laryngeal tuberculosis by an ozone method, this form of treatment is worthy of attention. Dr. Pfannenstiel gives an iodide by the mouth, and then exposes the patients to air containing ozone for several hours a day, by keeping them in a room in which an ozone apparatus is maintained at work. The ozone reacts with the iodides to liberate iodine, and the method is therefore a method of liberating nascent iodine in the tissues at the points where the ozone comes in contact with the iodides. It is reported to have given satisfactory results.*

* See *British Medical Journal*, March 23, 1912, for an article on this treatment, with references.

CHAPTER IV

THE UTILIZATION OF THE ELECTRIC LIGHT MAINS

Regulation of pressure and of current—Use of shunt circuits—Transformers—Motor generators—Multostats and polystats—Dangers of electric light mains—Accumulator charging—The aluminium cell—Electric lamps in therapeutics—The Finsen lamp—The Cooper-Hewitt lamp—Kromayer's quartz lamp.

85. **The Use of the Mains.**—Those who live in a place where there is a public supply of electricity are spared the difficulties associated with the maintenance of primary batteries, and only require to know the capabilities of the supply at their command, and how best to adapt it for their professional requirements. For this it is necessary to know whether the public supply is direct or alternating; secondly, the voltage or pressure of the supply; thirdly, in the case of alternating current, the periodicity or frequency of the alternations. In an Appendix a list is given of the public supply stations in Great Britain and Ireland, with particulars of these details. Much progress has lately been made in the design of medical apparatus for use on electric light mains, both for the direct and alternating systems of supply.

The difference between direct and alternating current is that in the former there is a steady flow of current from the one conductor or lead through the lamp, or other appliance, to the other. The one wire is always positive, the other always negative. In the alternating supply the current flows in a series of pulsations, first in one direction and then in the other, each wire being in turn either positive or negative (§ 52). The pressure at which electric lighting current is now supplied to houses is usually 200, 220, and 240 volts. At 200 volts a given current represents twice as much energy as the same current at 100 volts, so by raising the voltage of supply the conductors are enabled to carry a greater load without the need for increasing their sectional area, as would be necessary if they had to carry a greater magni-

tude of current. There is no advantage at all to the consumer from the higher voltage, but rather the reverse, but the advantage to the supply companies in the saving of capital outlay on copper for mains is considerable.

86. **Reduction of Pressure—Resistances.**—In almost all applications of the current to medical practice the first need is for a means of reducing the pressure. The pressure of supply is too great for most medical purposes. In order to reduce the pressure resistances are employed, for by means of the resistances in a circuit the magnitude of the current in the circuit can be regulated. Thus a resistance of 100 ohms in a circuit of 100 volts will prevent the current from exceeding one ampère, and a resistance of 100,000 ohms will cut down the current to one milliampère, and so on.

It is important to distinguish between the effect of a resistance in cutting down the current in a circuit, and its effect in lowering the voltage in a circuit or portion of a circuit. In § 28, when treating of the internal resistance of cells, an attempt was made to draw this distinction, and it may now be repeated that the effect of resistance upon the voltage in any part of a circuit is a relative one—that is to say, the fall of volts in a part of a circuit, such as a resistance, depends upon the resistances in the other parts of the circuit, and may be estimated by comparing the resistance of the part under consideration with the resistance of the rest of the circuit. For instance, take a resistance of 99 ohms interpolated in a circuit of 100 volts, when the resistance of the remainder of the circuit is very small, say, for purposes of illustration, one ohm, then the drop of volts in the resistance will be 99 volts. But if four such resistances be inserted in different parts of the same circuit then the drop in volts at each resistance will no longer be 99 volts, but will be one quarter of that amount, and the fall in the potential from 100 to 0 will take place in four steps of about 25 volts, one at each resistance. It follows from this that a resistance intended for regulating the voltage in any part of a circuit must be made proportional to the resistance of the circuit to be regulated. If the resistance of the part to be regulated is 50 ohms, then a resistance of 50 other ohms will halve the voltage acting on it, but a resistance of 50 ohms will not equally halve the pressure if the other part has a resistance of 950 ohms, for in this case the fall in volts at the first resistance would be only one-twentieth of the total electromotive

force of the circuit, while the second portion would bear a pressure of nineteen-twentieths of the total. A resistance which is suited for the regulation of the current of a lamp will not serve to regulate current through the human body. In the first case a few ohms will suffice, in the latter several thousand ohms are necessary.

It was stated in § 25 that the energy expended when a current passes through a resistance appears for the most part in the form of heat. Resistances, therefore, become heated when in use, and the heating effects must be carefully borne in mind and the resistances so designed as to carry the currents they are meant to regulate without excessive heating. A resistance suitable for a current of a few milliampères might be burnt out if a current of one ampère were passed through it. From their cheapness and convenience incandescent lamps are often useful for resistances as they are not injuriously affected even by great heating, and in almost all resistances for medical work from the mains a lamp forms part of the circuit, being combined usually with a coiled wire resistance which admits of adjustment. On a circuit of 200 volts an eight-candle-power carbon filament lamp will cut down the current to about 0·15 ampère, a sixteen-candle lamp to 0·3, and a thirty-two to 0·6. As a rough approximation the resistances of incandescent lamps when hot (§ 23) may be taken as follows: For 100 volts—an eight-candle lamp, 320 ohms; a sixteen, 160 ohms; a thirty-two, 80 ohms. With 200-volt lamps the resistances are four times as great, and the currents are therefore halved.

87. **Regulation by Shunt Resistances.**—The ordinary way of using a resistance is to put it in series with the apparatus to be protected (§ 64). The whole current then passes first through the resistance and then through the apparatus regulated, and for many purposes a simple resistance in series gives all the regulation that is wanted. But another way of using resistances is to have them as a shunt or bridge to the piece of apparatus, the current dividing and passing in part by one channel and part by the other. This is known to engineers as the "potentiometer" method of regulation. When two circuits are arranged in this way in parallel, either of them is said to be "in shunt" to the other, or "shunted by" the other. Arrangements of resistances in shunt to apparatus are often useful, or two resistances may be used in series with each other, the patient (or the piece of apparatus) being arranged as a circuit in shunt to one of

them, and Fig. 79 shows such a combination of shunt and series resistances. The current from the main passes from the positive pole of the supply through a switch to A. From A to B is a resistance of wire, and B is a lamp which the current traverses to reach the negative pole, after passing through a fuse. Thus there is formed a closed circuit through the two resistances of the wire coil and of the lamp, with a fall or slope of potential between A and B, and a further fall through the lamp at B, the total fall being from 100 volts to zero on a 100-volt circuit. The circuit for the patient is arranged in a shunt to the wire resistance, or to a part of it, and the voltage applied in the patient's circuit will vary as the traveller C is moved along its metal slide.

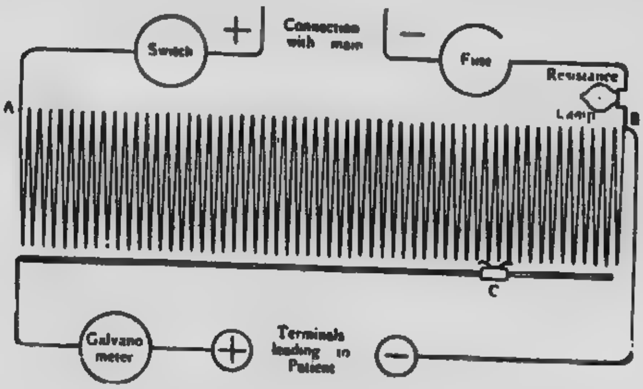


FIG. 79.—PLAN OF RESISTANCE IN SHUNT TO A PATIENT.

Let us suppose that the coils depicted are 450 in number, and that their resistance is nine times as great as that of the lamp B, then assuming our pressure at the main to be 100 volts, the drop of volts in the lamp will be 10 volts, and in the coils 90 volts. With 450 loops in the wire the fall of volts is one-fifth of a volt per loop—that is to say, there will be a potential difference of one-fifth of a volt between any loop and the next. If the loops were 4,500 in number then the potential differences would be as one volt for every 50 loops, and so on. The potential difference between C and B through the shunt circuit would increase as the traveller C was moved further towards the A end of the coil, because it would "tap" the slope of potential at a higher level, so to speak, and the more numerous the coils of A and B the more finely could the volts be adjusted to suit any needs of the shunt circuit.

In shunt circuit regulation energy is continuously wasted, because a steady flow of current along one of the two conducting paths is necessary in order that the flow along this path, which may be called the regulating circuit, shall provide the gradual fall or slope of potential which is to be tapped for the other or utilization current.

With certain structural variations, chiefly in the number of the windings and the thickness of the wire, this method will suit all the cases which require a low pressure to be obtained from the electric light mains. The lamp acts as a safety resistance, and determines the maximum current which can pass through the apparatus. A certain latitude is afforded by the use of lamps of various candle-power for that portion of the resistance. When the current is to be applied to the lighting of a small surgical lamp which requires, say, an ampère, the safety lamp must be of such a character as to permit that amount of current to pass it, and the resistance wire must also be stout enough to carry that current without heating. When a cautery is to be heated, no lamp is arranged in series with the wire, and the various parts must be on a much larger scale, because they may have to waste energy at the rate of several horse-power when in use, and the current of five, ten, or twenty ampères which a cautery requires has considerable heating effect upon the wires which lead to the cautery, as well as upon the cautery burner itself. The whole apparatus, therefore, becomes heavier and more expensive to make.

When large currents are required, the advantages of a shunt circuit over regulation by resistances in series becomes even more evident for certain applications. In the case of a galvano-cautery requiring ten ampères to heat it, the current from the 200-volt main could be choked down to the required magnitude by a resistance of twenty ohms in series with the cautery instrument but to use it in this way would be dangerous. Ten ampères of current are quite sufficient to maintain an electric arc across a small air-gap, and it might easily happen that on breaking the circuit in the usual way with a key in the handle of the cautery instrument an arc would be established at that point which would instantly destroy the handle. Or, again, if from any cause the platinum of the cautery should break or fuse during its use, the establishment of an arc, with an accompaniment of drops of fused platinum

and copper in contact with a patient, might have serious consequences.

Shunt circuit instruments for use with heavy currents are made as a rule of a number of open coils of thick iron wire affixed to the back of a slate or marble slab, with ample air spaces for ventilation, by which means the heat generated in the coils is dissipated. The coils are joined together in a series, and at intervals a connection is led off to a stud on the front of the switchboard, whence the current is taken to the appropriate binding-screws through a moving crank arm (Fig. 80).

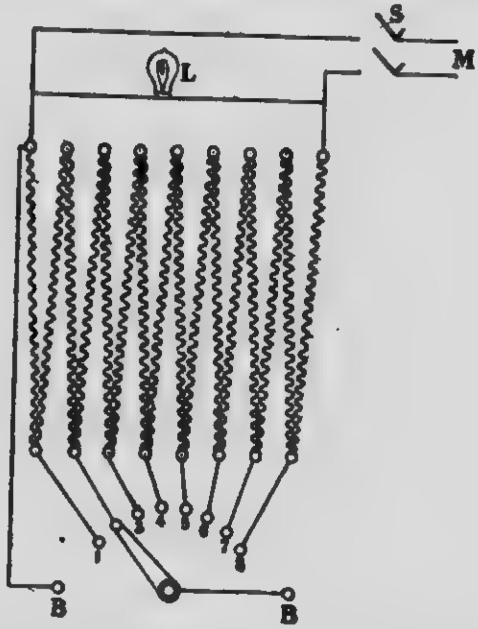


FIG. 80.—PLAN OF SHUNT RESISTANCE FOR LARGE CURRENTS.

M, Mains ; S, switch ; L, pilot-lamp ; B, B, terminals.

In this figure the wire coils of the shunt circuit are composed of sixteen lengths of a spirally-coiled wire. If the potential difference between the positive and negative wires of the source is 200 volts, the difference of potential existing between the two ends of each section will be one-sixteenth part of the total, and between the beginning and end of a double section one-eighth of the total, or, in the case under observation, 25 volts, and thus the row of studs numbered from 1 to 8, which are connected to points on the resistance, provide places from which current can

be drawn at any one of a series of intermediate voltages. When the crank arm stands on the stud numbered 1, the difference of potential between the terminals B, B will be one-sixteenth of the total pressure supplied by the main, or a little over 12 volts, and when it stands at the second stud, as shown in the figure, the difference of potential between B and B will be 37·5 volts.

A lamp is often fitted to the switch-board to indicate that the current is on through the coils. This is useful in order to prevent unnecessary waste. The coils of wire form a closed circuit, and according to the number, length, and thickness of the iron

Fig. 81.—Shunt Resistance, for Medical Treatment, with Galvanometer.

wire coils the flow of current through them may be ten or twenty ampères or more. A voltmeter and ampèremeter and a safety fuse are added, and in some cases an adjustable resistance for further regulation in the utilization circuits is used to make the switchboard complete.

A simple resistance apparatus on the shunt resistance principle is shown in Fig. 81. It can be used for direct applications of "galvanic" currents to patients, and is provided with a milliampèremeter.

An illustration of a more complete apparatus is shown in Fig. 82, which contains shunt resistance for regulation, milliam-

pèremeter, induction coil, commutator, and box for cords and electrodes. The apparatus can also be arranged on a table or fitted as a switchboard to attach to a wall.

The induction coils supplied on these switchboards are not always of good design. Coils for medical use should be wound with short lengths of wire, and should have a quickly moving

FIG. 82.—COMPLETE FITTING FOR UTILIZATION OF DIRECT CURRENT MAINS FOR MEDICAL USES.

interrupter, and a core containing a very moderate amount of iron (§ 61).

The milliampèremeter must be guarded against short circuits, as these would be very likely to overheat and destroy the windings of the galvanometer coils.

It might be thought that regulation of current in the ordinary way by resistances in series with the patient would be sufficient for general medical purposes.

For instance, a current of 5 milliampères could be applied to a patient from a 200-volt main by using a cheap graphite re-

sistance (Fig. 46) of 40,000 ohms, but the effect upon the patient would be disagreeable; for if the resistance of the skin were high, as is frequently the case, it would be subjected to a high electromotive force until the skin resistance had been reduced by thorough moistening of the surface. Pain would be felt, and blistering possibly produced. On the shunt circuit this is not the case, for the operator can commence with a low electromotive force, which can be gradually raised as high as may be needed, so that the initial application of a high voltage to a badly conducting skin surface is avoided.

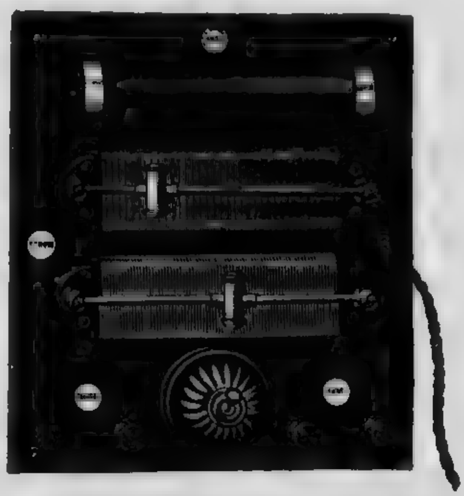


FIG. 83.—TRANSFORMER, WITH TWO SLIDING RESISTANCES, ONE FOR CAUTERY INSTRUMENTS AND ANOTHER FOR SMALL LAMPS.

88. **Alternating Current—Transformers.**—The general principles of the transformer have been mentioned in § 53, and, as might be expected, it is often of use in medical work.

The commonest type of transformer for medical use is a "step-down" apparatus, or one which is used to convert a small alternating current at the pressure of the electric lighting mains into a larger current at two or four volts for cauteries, or at eight or ten volts for small incandescent lamps, or to generate sinusoidal current at a low pressure for use in the electric bath (§ 68).

The first transformer specially designed for medical use was Woakes' transformer, which dates from 1891. It had several secondary coils upon one bobbin—one for cautery to give about four volts, and wound with thick wire to carry a heavy current

without heating; one for small lamps, and one for therapeutic purposes. Each secondary had its own terminals, and all were excited by one primary coil. Regulation was effected by a sledge movement of the secondary bobbin like that of a medical coil. In other forms of medical transformer the iron core is not straight as in Woakes' pattern, but is a circular ring of laminated iron. This is more efficient electrically, and regulation can be done by a separate resistance, as is done in the instrument shown in Fig. 83.

Transformers for high pressures or "step-up" transformers are used in medical work for the production of X rays, for certain forms of spark lamps used in treatment, and for high-frequency

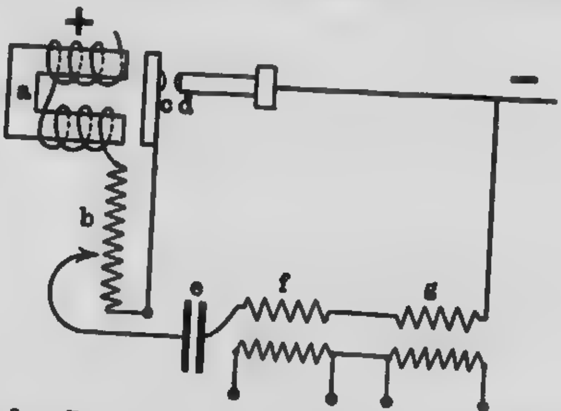


FIG. 84.—PLAN OF CONTINUOUS CURRENT TRANSFORMER.
a, Electromagnet; *b*, resistance; *cd*, interrupter; *e*, condenser; *f*, *g*, primaries of transformers.

currents. These transformers will be considered in the succeeding chapter.

On the direct current mains a transformer can be used if an interrupter be combined with it, and the transformer can then be employed for cautery and lamp instruments, but the current is too irregular for use as sinusoidal current for patients. A modified apparatus made by Mr. Leslie Miller works very well. It resembles a small coil, but the primary circuit is not continuous, being interrupted by a condenser. The current into the primary is therefore limited by the capacity of this condenser, which continues to be charged and discharged by the movement of the vibrating hammer. Fig. 84 shows the arrangement of the windings. This instrument is an improvement upon the older

forms. They have been mostly superseded by the machines of the multostat type described below.

89. **Sinusoidal Current.**—The sinusoidal current (§ 52) supplied by the alternating current mains usually has a frequency ranging between 50 and 100 periods per second, and a sinusoidal current of this periodicity is quite suitable for most kinds of electrical treatment. It is the best form of current for simple stimulation of living tissues, particularly when it is given with rhythmic interruptions, as described in § 72. Sinusoidal current is quite agreeable when applied in an electric bath, or through the ordinary moistened electrodes, if these are of good size, but is rather painful when used for the testing of nerve and muscle. When muscles are tested the sensation is unpleasant, owing to the combined effect of the long waves of current (§ 62) and of the concentration of the current at the surface of the small electrode used, though when the concentration is reduced, as in treatment by the use of large electrodes or of baths, the stinging effect is not noticed.

There is no reason why sinusoidal currents of lower periodicity should not be employed in treatment, except the fact that they must be specially generated. On systems of public supply the periodicity must be above a certain minimum of about forty in order that the lamps supplied by the system may give a steady light. Dr. Reginald Morton has advocated* the use of sinusoidal current of the very low frequency of 1·7 cycles per second (102 periods per minute), and considers it to be specially indicated when it is wished to stimulate unstriped muscle—as, for instance, the unstriped muscle of the intestine—or striped muscle which presents the reaction of degeneration, and is therefore incapable of responding to currents of brief duration.

90. **Polyphase Currents.**—A few words on the subject of three-phase currents may be useful, because it is possible that their employment for medical purposes may become extended in the future. Polyphase currents of low periodicity have been recommended for treatment by Dr. George Herschell, particularly for the treatment of abdominal conditions.†

In § 49 it was mentioned that a direct current dynamo is fitted with a commutator, and an alternating current dynamo is fitted with two insulated metal rings from which the current is

* *Archives of the Roentgen Ray*, March, 1907.

† "Polyphase Currents in Electrotherapy." London : Glaisher, 1903.

collected. These "slip rings" can also be fitted to a direct current motor on the shaft at the opposite end to the commutator, and can be used to draw off alternating current from the motor when it is running. The slip rings are joined to opposite points upon the windings of the armature. If three slip rings were fitted and these were joined to three equidistant points upon the armature windings, alternating current could be collected from any two of the slip rings—that is to say, there would be an alternating current between 1 and 2, another between 2 and 3, and a third between 1 and 3. The three currents are successive in point of time, but overlap each other, one growing as the others fade; and by means of three conductors this "three-phase" system of currents could be applied to three regions of a patient's body. If necessary, the currents might be regulated by a triple transformer, with three iron cores, and three sets of primary and secondary windings.

91. **Transformation of Pressure—Motor Generators.**—The reduction of the pressure of the supply mains can also be effected

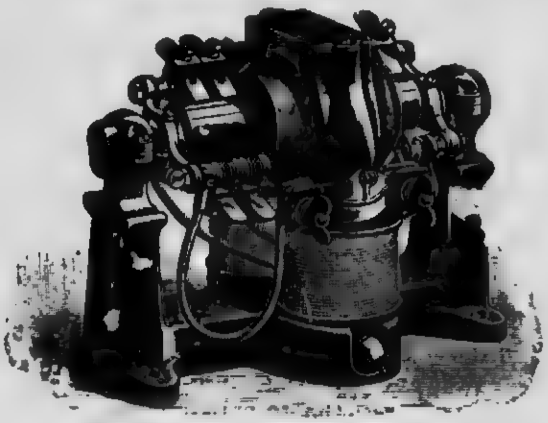


FIG. 85.—MOTOR GENERATOR.
Two sets of windings upon one framework

by conversion or transformation. In § 53 it was explained that one great convenience of alternating currents was the ease with which they can be made to induce fresh alternating currents at a different voltage by means of a transformer. In the case of direct current the same thing can be done, though in a more roundabout way, for whereas the transformer used with alternating current is a simple and stationary device, with direct

current a moving machine or "motor generator" must be used. In spite of this extra complication, the motor generator has been specially adapted to medical requirements, and fulfils its purpose admirably.

Briefly stated, a motor generator is an electric motor whose movement is used to generate a new current of some other character than that supplied to it. In some cases it consists of two machines coupled together, one to act as motor and the other as dynamo; or a single machine may be used if it have two sets of windings upon the same framework, and is fitted with two commutators, one for the motor windings and the other for the generator windings (Fig. 85).

By means of a suitably wound motor generator a supply of direct current can be obtained from the alternating mains, and, conversely, a supply of alternating current from the direct current mains. This is of great advantage to medical men, because both types of current are needed in medical practice, and in the vast majority of cases only one form of public supply is available.

The uses to which the current from the mains may be applied are as follows:

1. To replace medical batteries and coils in applications to patients.

2. To provide sinusoidal current (§ 52) for purposes of treatment.

3. To illuminate the small lamps used in diagnosis, such as cystoscopes, antrum lamps, etc.

4. To heat galvano-cauteries.

5. To drive motors for mechanical massage, for surgical and dental drills, saws, and trephines, and to operate small pumps for Bier's treatment, for the so-called pneumatic massage, for sprays, fans for hot air, etc.

6. To charge accumulators.

7. To operate arc lamps and other special lamps for the employment of light in treatment.

8. To drive Ruhmkorff coils or other machines for X-ray and high-frequency work.

The first five of these uses can be had from one of the modern motor generator sets, which are now made or supplied by the firms interested in electro-medical apparatus, under the names of "pantostat," "polystat," "multostat," and so forth (Figs. 86, 87).

The uses of the mains for the charging of accumulators and for the lamps of high voltage used in phototherapy will be considered immediately, and the uses of the mains for Ruhmkorff coils is dealt with in the next chapter.

92. **The Pantostat or Multostat.**—These machines consist of a motor generator constructed to suit the character of the electric supply in the place where it is to be used. If the supply is of direct current, a direct current motor is used, and it generates an alternating current to supply a transformer which in turn

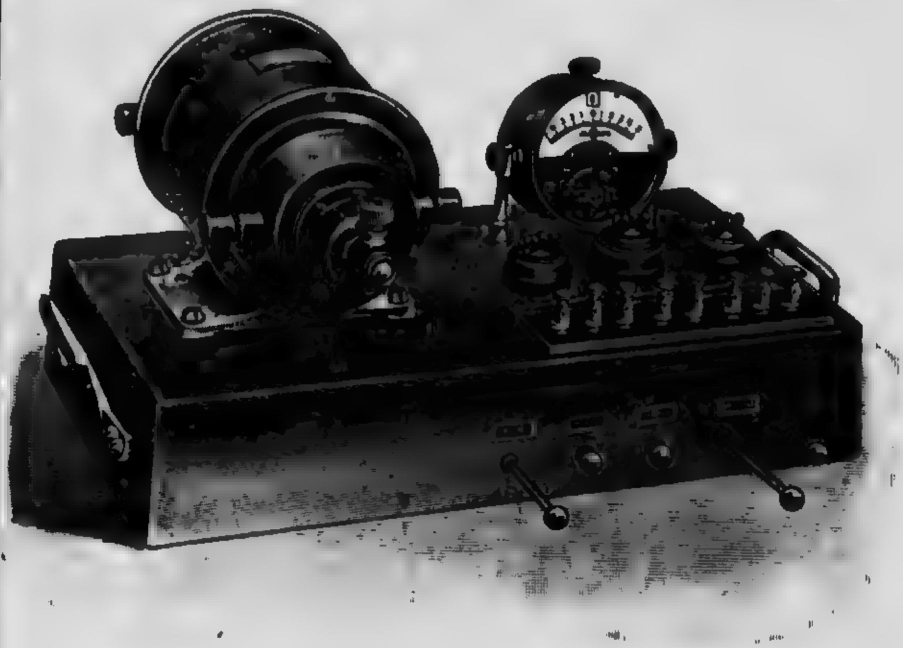


FIG. 86.—PANTOSTAT.

gives currents for heating a cautery, for exploring lamps, and for sinusoidal applications, and the motor can also be wound to give a direct current of reduced pressure suitable for applications of galvanization, ionization, and for the testing of nerve and muscle. In all cases the currents are independent of the current which drives the motor, and this protects the patients from shocks through leakage from the mains to earth.

In order to render the direct current smooth and even, a condenser is included in the apparatus, and this is connected across the poles of the "continuous current" treatment circuit.

This condenser is necessary to smooth away the variations of current which are inevitable when current is generated by a dynamo of small size, owing to the fluctuations of potential which occur as the commutator segments move past the collecting brushes. Suitable switches and regulating devices are provided on the base board of these machines, to adapt all the currents provided for safe and convenient application. Mr. Schall pro-

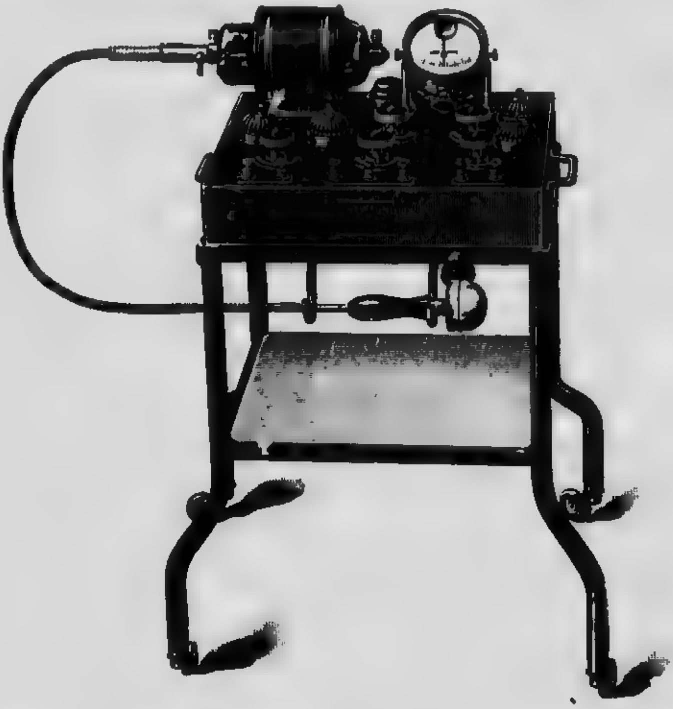


FIG. 87.—UNIVERSAL APPARATUS, WITH FLEXIBLE SHAFT FOR MECHANICAL MASSAGE.

vides a rhythmic interrupter (§ 72) to his form of instrument, the movement being obtained from the motor of the apparatus.

When the supply from the mains is alternating, it is not necessary to set the motor in action except for the generation of direct current, as a suitably designed stationary transformer is included in the outfit, and suffices to provide the low pressure alternating currents required for lamps, cauteries, and for applications of sinusoidal current. With these currents the protection of the patient from leakage to earth is brought about by the

careful insulation of the secondary and primary windings of the transformer.

93. **Dangers of Electric Lighting Mains.**—In all applications of current from the mains to patients it is necessary to take proper precautions to prevent accidents. These may arise from defects in the design of the apparatus, either inherent, or as a result of wear and tear, from loose connections, etc. Care must always be taken to avoid the risk of discharges to earth through a patient, as it is quite possible to have things so arranged that the patient might receive a dangerous discharge from one pole of the apparatus to earth, even when employing resistances in such a way as to prevent dangerous discharges from pole to pole through a patient. For instance, if all the safety resistance should be on one side of the patient, and there were none on the other, an accidental contact of the patient with a good earth, as through a gas or water pipe, a radiator, or a damp wall or floor, might expose him to a leakage to earth at the full pressure of supply.

On circuits of 100 volts this is bad enough, but when the differences of potential possible in a lighting company's network are 200 or 240 volts, or more, it becomes obvious that the danger is not an imaginary one.

Another matter to be attended to in shunt circuit regulation is the maintenance of the continuity of the resistance wire. If it should break from any cause, or become disconnected at one extremity, the patient might receive the full pressure of the mains, if his circuit bridged the interval of the gap. By the use of two shunt resistances coupled in parallel, the safety of the apparatus is much increased. In general, the lamp resistance provided on the shunt circuits acts as a safety indicator. If it should not light up as usual, it must be taken as a warning that something needs attention.

With electric baths, where the patient is largely deprived of the protection generally afforded him by the resistance of his skin and clothing, special attention must be given to the dangers of shock to earth.

It is unsatisfactory to attempt to insulate a bath if it is fitted with metal water-pipes and waste pipe. It must be permanently earthed, and protected efficiently from that point of view, if it is to be a safe appliance.

For sinusoidal current baths protection may conveniently be

ensured if the regulating transformer be made with a sliding secondary coil having an air space or an ebonite sheath between it and the primary windings. With direct current mains much security will be afforded by the use of a battery of accumulators instead of the mains for the bath. These may be charged from the mains as required, but should be provided with an interlocking safety switch to compel the cutting off of the mains current before the bath circuit can be connected. The "earth-free" types of multostat are also safe when used for direct current baths.

Quite apart from the matter of electric baths, it may be laid down as an axiom that no metal connected in any way to an electric light fitting should be in reach of any person in a fixed bath of any kind. Electric light switch covers may be alive, from some defect, and if so a person touching one when in a bath with metal pipes and taps connected to earth, or when standing on a wet stone floor, might easily receive a dangerous shock.

An accident occurred at the Fulham public baths at the end of 1902 in this way. Two men standing in water, or on a wet bathroom floor, touched an iron pipe, which happened to be alive through defective wiring arrangements for the lighting of the building, and both were killed by a pressure of 200 volts. Dr. Pinto Leite has recently reported* a similar experience, though, happily, not fatal. When standing up in his bath, he accidentally touched an electric light switch with his wet arm, and received a violent shock. He says: "All the muscles of the right side of my body seemed clutched by an invisible power, and I was flung violently down into the bath. I have no recollection of coming into contact with the bath, and can only remember that, on coming to realize my position, I found myself breathing hard and deep, at the same time feeling a curious tingling sensation all over the body, and a soreness of the muscles." He mentions, too, that he received a similar shock in the same way some months later. The pressure of the supply was 210 volts.

94. **To Charge Accumulators.**—It is often convenient to use the direct current to charge accumulators, which can then be detached from the mains and used independently, as, for example, for providing a portable apparatus to take to a patient's house. Although a desire for absolute uniformity of practice, or the idea of saving one's self trouble, might make one wish to use current

* *British Medical Journal*, September 24, 1910.

from the mains only, without any accumulators, the advantages on a practical side all lie in a combination of the two methods—that is to say, in the use of accumulators for some purposes, and in direct applications of the current from the mains in others. Thus the simplest way for lamp and cautery work is to charge a portable accumulator from the mains, and then to use the accumulator for the lamps or cautery. Many surgeons only need current for these purposes, and with a portable accumulator and a lamp-resistance for recharging it they can be fully equipped at a small outlay.

To charge an accumulator from the direct current mains the battery must be connected so that the current which goes

FIG. 88.—LAMP SOCKET FITTING WITH CONNECTIONS FOR CHARGING SECONDARY CELLS FROM THE MAINS THROUGH THE LAMP.

through it must also go through a resistance, the favourite form for this being an incandescent lamp. In the case of a lamp supplied from a flexible cord the conditions would be met by cutting one part of the double wire, and untwisting the cut ends for a few inches, so as to give sufficient length for connection to the two ends of the battery. As one of the severed ends is positive and the other is negative, there will be a right and a wrong way of connecting up. When once determined, the polarity of the ends may be marked in some way for future guidance. The best way of testing the polarity of the ends of wire is to use moistened litmus-paper ; the paper will be stained

red where it touches the positive pole, and blue where it touches the negative (§ 65).

Ready-made appliances for charging through a lamp can be bought at the instrument-makers. Some consist of a board carrying one or more lamps in sockets, with a pair of charging terminals, and a flexible wire with plug for attachment to wall-socket or lamp-socket, as may be desired. A form of adapter with binding-screws to insert in a lamp socket (Fig. 88) is also made for the purpose; the path of the current through such a fitting may be understood readily from Fig. 89. It is as well to bear in mind that with the ordinary two-prong wall-plug, and

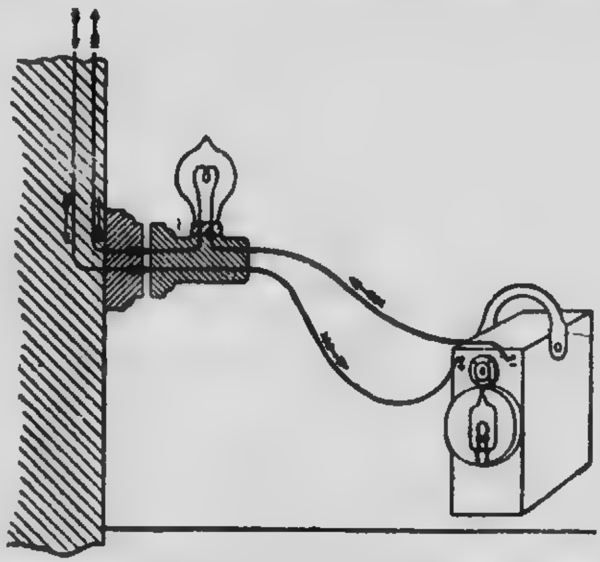


FIG. 89.—ARRANGEMENT OF WIRES IN CHARGING SOCKET.

also with the bayonet-catch lamp-socket, there are two possible positions of insertion of the lamp or plug, and therefore the polarity of the binding-screws is not always the same.

The charging current through a 16 candle-power carbon filament lamp on a 100-volt circuit is about 0·6 ampère, on a 200-volt circuit about 0·3 ampère, on a 240-volt circuit about 0·25 ampère. The current can be increased by the use of a number of lamps arranged in parallel to one another, or more simply by the use of a lamp of higher candle-power. For purposes of rough calculation a 32 candle-power lamp carries twice the current of a 16, and so on in proportion. Carbon filament lamps are more

convenient to use when charging, as they are cheaper, and allow more current to pass than is the case with metallic filament lamps.

When the charging of the cells from the mains is to be done frequently, it may be worth while to have the charging terminals connected to one of the house lamps which is in regular use, in order not to waste energy.

95. **Accumulators and Alternating Current.**—The aluminium cell is a valuable contrivance for charging accumulators from the alternating mains, for without some special device the alternating current cannot charge an accumulator. This contrivance owes its value to a peculiar behaviour of aluminium, by which it offers a very high resistance to the passage of a current when acting as the anode of an electrolytic cell, although as kathode it offers no such resistance. Accordingly an electrolytic cell having aluminium for one pole, and another metal or carbon for the other, will tend to arrest the passage of an alternating current through it in one direction, while readily permitting a flow in the other direction. A cell with both poles of aluminium permits no current to pass, and acts as a condenser ot large capacity. This property of aluminium has been known for many years, having been discovered by Buff in 1856. Its practical application to alternating currents was suggested by Ducretet in 1876, and later by Graetz, Pollak, Nodon, and others.

A simple aluminium cell can be made of a rod of aluminium immersed in a jar of saturated ammonium phosphate solution, with an iron plate for the other pole. With such a cell arranged in series with a resistance, as, for example, with a lamp-resistance like that shown in Fig. 88, the alternating mains can be used to charge an accumulator if the aluminium cell is so connected up that the direction of flow from iron to aluminium is towards the positive terminal of the accumulator, and a direct current ammeter in the circuit will give readings of the mean charging current.

As half the impulses are arrested by the cell, the readings will be half of those for which the candle-power of the lamp is rated (§ 86); thus, with a 32 candle-power carbon lamp on 100-volt mains the accumulator will be charged at the rate of about half an ampère.

By using a combination of four cells both phases of the current

can be utilized in one circuit, as suggested by Graetz (Fig. 90). It is an application of the principle of the Wheatstone bridge (§ 44). The cells are arranged in a circuit, as shown at K, the direction from iron to aluminium being indicated by the arrows. The alternating current is applied at A and C. No current can pass in either direction, for it is opposed by one or other of the aluminium cells, but if B and D be connected a current will flow from B to D. When A is the positive pole, the flow will be by A B, D C, and when the electromotive force is reversed and B is positive, it will flow by C B, D A, always, therefore, from B to D through any circuit joining B and D. The system

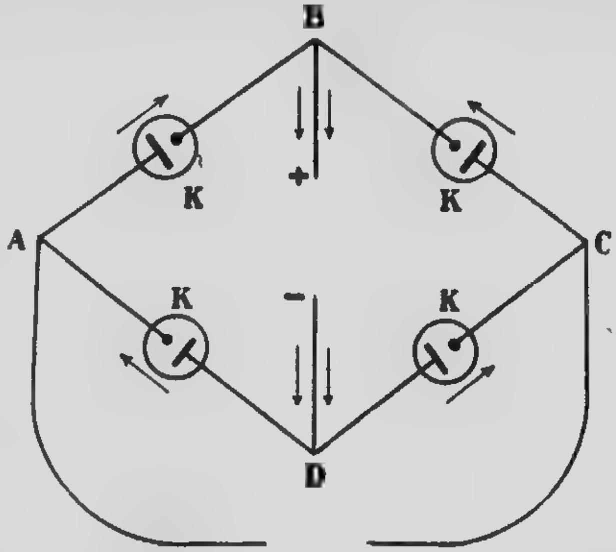


FIG. 90.—ARRANGEMENT OF ALUMINIUM CELLS IN NODON VALVE.

may be regarded as a Wheatstone bridge circuit, in which the resistances automatically change with the changes of sign of the alternating electromotive force applied at A and C. The Nodon valve and Pollak's rectifier are arrangements of aluminium cells on this principle. The current given out by these forms of rectifier is pulsatory but unidirectional.

Fig. 91 shows a simple arrangement by which two cells can be used instead of four for charging accumulators. K K, as before, are the aluminium cells ; they are oppositely arranged on two branches of one of the conductors of an alternating circuit ; the other conductor is joined through a resistance to the middle

point of a set of accumulator cells. It will be seen from the diagram that the impulses of current will pass alternately into one or other of the accumulator sets, and will charge each in turn.

When the cell has been in action for a time, the ammonium phosphate solution gives off ammonia, and becomes acid. Some

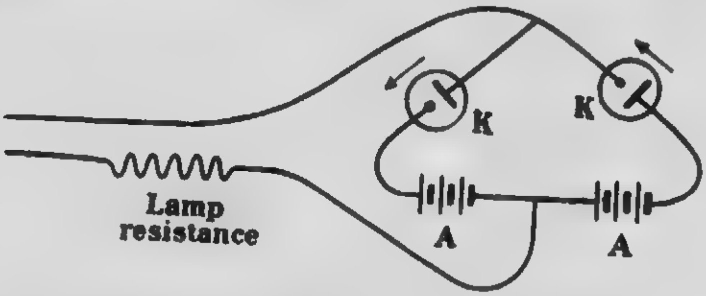


FIG. 91.—ACCUMULATOR CHARGING WITH TWO ALUMINIUM CELLS.

aluminium phosphate is formed, and a crystalline precipitate gradually incrusts the interior of the cell. If the electrolyte is kept in order by frequent small additions of weak solution of ammonia to make the solution neutral and to take the place of the

FIG. 92.—ALUMINIUM RECTIFIER.

water lost by evaporation, this incrustation will be much diminished, and instead there will be merely a slow precipitation of alumina as an amorphous sediment. Chlorides are unfavourable to the valve effect, and distilled water must be used in preparing the electrolyte.

For good rectification the area of the aluminium should be small, so that the density of current per unit of surface is high. On this account a slender rod of aluminium is to be preferred to a sheet or plate of the metal, particularly when the currents to be rectified are not much more than one or two ampères. On circuits of 200 volts it would be economical to transform down to 50 volts before rectification, as this procedure would give four ampères for one, subject only to losses in the transformation. A single cell will not rectify at pressures above 100 volts.

The capacity (§ 11) of the aluminium valve cell is remarkably high. Apparently the rectification is due to the formation of a very thin non-conducting film of aluminium oxide on the surface of the metal when it is acting as the anode, and this film produces a condenser effect so that a large electrical capacity can be obtained by the use of the aluminium cell.

If the aluminium rod be viewed in the dark when the cell is working, it will be seen to be covered with a luminous glow, which is most marked when the cell is rectifying against a fairly high back electromotive force.

96. **D.C. Small Lamps.**—From what has been said in the section on charging accumulators (§ 94) it will be recognised

FIG. 93.—RHEOSTAT FOR SMALL LAMP.

that the use of a small portable accumulator presents distinct advantages for use with incandescent-lamp instruments. They may also be operated quite easily from the mains by reducing the current in a simple regulating series resistance. This resistance is usually combined with an ordinary incandescent lamp. The lamp is a form of resistance which offers a convenient way of dissipating the energy which has to be wasted. In cases where its light would be inconvenient a lamp of red or blue glass can be substituted. The lamp chosen must allow the passage of a current sufficiently large to bring the smaller surgical lamp to incandescence, and the best result is obtained with a carbon filament lamp for the resistance and a metallic filament lamp for

the instrument itself. This method of using lamp instruments from the mains involves risks of leakage currents to earth, with shocks to the operator holding the lamp, if he should be standing on a damp floor, or should touch metallic objects connected to earth, and although this may not matter in a carpeted room, it is inconvenient in an operating-theatre.

Fig. 93 illustrates a rheostat described by Mr. Crawford Renton,* for use with the cystoscope. The rheostat can be used upon any ordinary electric light circuit, and the current is reduced through a 50 candle-power lamp. Mr. Renton states that the cost of the rheostat is only 30s.,† and that it is easily carried in an ordinary small operating-bag.

97. **Lamps for Therapeutic Applications.**—Incandescent lamps may be used as a source of warmth as well as of light. Foot-warmers fitted with an incandescent lamp instead of the usual

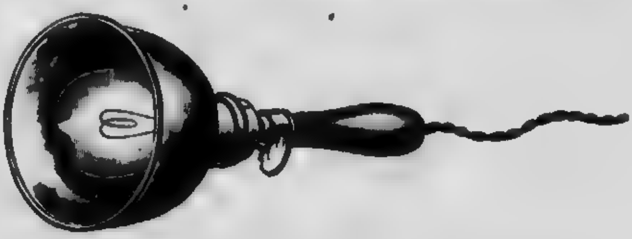


FIG. 94.—HAND-LAMP FOR THE LOCAL APPLICATION OF HEAT AND LIGHT.

hot water have obvious advantages, and the principle may be extended almost indefinitely for purposes of applying heat continuously to various parts of the body.

Fig. 94 shows a form of hand-lamp which may be used for applying warmth locally for the relief of pain or other purposes, and Fig 95 shows an apparatus fitted with lamps for application to the abdomen.

For these applications of electricity the electric light mains are required, because the amount of energy consumed in them is considerable, and much more than could be conveniently provided from batteries.

It has been claimed that the light given out by incandescent lamps has a therapeutic value above that of the heat they afford, and the use of electric light cabinets in which the whole surface

* The *Lancet*, June 24, 1905.

† The maker is Mr. J. Trotter, 40, Jordan Street, Glasgow.

of the body is exposed to the light of incandescent lamps has been very largely advocated and pushed of recent years, especially by various interested persons. It is certain that the exposure of the body to the light of incandescent lamps is a very convenient way of stimulating the action of the sweat-glands, and the effects of the hot room of a Turkish bath may be produced very simply and easily by this means. Fig. 96 shows a "cabinet" for electric lamp baths. There is an opening at the top to allow the patient's head to emerge.

The earliest work on the use of incandescent lamps for sudatory purposes was done by Dr. Kellogg, of Battle Creek, in the United States, and his report on the subject was laid before the American Electrotherapeutic Association in 1894. He observed that active sweat secretion began within ten minutes from the time

FIG. 95.—ELECTRIC LIGHT WARMER FOR THE ABDOMEN.

of exposure of the body to the light of the lamps, and found that the average temperature in the bath-cabinet was about 80° F. instead of the 140° F., or higher, of the hot room of the Turkish bath. He also pointed out that the air was not only cooler but purer in the incandescent-lamp bath. It is not unlikely that the use of electric lamps may supersede the present Turkish-bath method of inducing perspiration.

In the treatment of disease the use of light and heat from electric lamps has been considerably developed in recent years. If the extravagant claims made by certain writers be disregarded, it still remains that for certain purposes the use of this method of treatment is of value, particularly in the treatment of stiff and painful joints and in sciatica.

98. **The Finsen Lamp.**—Arc lamps are also used for therapeutic purposes. With the arc lamp the violet and ultra-

violet rays are abundant, whereas they are absent or scanty in the light of incandescent lamps. The work of Finsen, of Copenhagen, has firmly established the fact that the concentrated light of the arc lamp, or of the sun, has a curative effect upon lupus, and it is to the labours of Finsen that we owe the introduction of light as a therapeutic agent into medical practice. Finsen's apparatus consists of a very powerful arc lamp, consuming as much as 80 ampères of current, and the light from the arc is collected by quartz lenses, and focussed upon a small area of

FIG. 96.—ELECTRIC LIGHT BATH CABINET.

the affected surface, which is kept cool and at the same time rendered anæmic by a quartz compressor through which cold water is kept flowing. The object of the compression is to press out the blood from the capillaries of the part under treatment, and so to facilitate the penetration of the light rays to a greater depth than would be possible in the presence of the blood, which absorbs the violet rays of the spectrum.

The great size and cost of an installation like that of Finsen has led to many attempts to obtain equally good results with

simpler forms of apparatus. Arc lamps of moderate size have been manufactured under the names of the Lortet-Genoud lamp and the Finsen-Reyn lamp. The latter, which is the approved form of small arc lamp used in Copenhagen, is shown in Fig. 97.

99. **The Condenser Spark-Lamp.**—Although the success of the treatment of lupus by the Finsen method is undoubted, yet its application is extremely tedious.

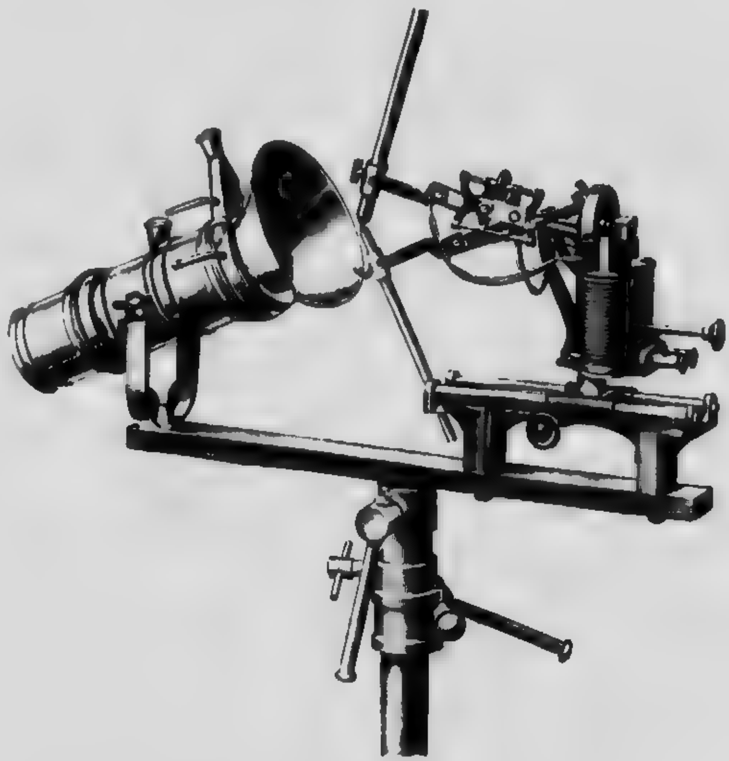


FIG. 97.—THE FINSEN-REYN FORM OF ARC LAMP.

In the first place, the sittings must be of long duration, thirty minutes or an hour ; secondly, the part treated at one sitting is only about one square inch, and the number of applications necessary to obtain a cure is very great. For all these reasons there have been many attempts to improve upon the method, and it is by no means certain that the unmodified Finsen method of treating lupus will survive the test of time.

Lamps with electrodes of metal to augment the output of ultra-violet rays have been devised by several inventors.

The "Dermo" lamp is an arc between electrodes of water-cooled iron. Bang's lamp and that of Broca and Chatin are of somewhat similar character.

The condenser spark-lamp known as the St. Bartholomew's lamp, made by Mr. Leslie Miller (Fig. 98), makes use of the well-known physical fact that condenser spark discharges are especially rich in the spectral lines of their metallic sparking

Fig. 98.—The Condenser Spark-Lamp.

points. It consists of a cylindrical metallic holder enclosing a pair of iron rods between which a stream of condenser discharges is maintained. The end of the tube is closed by a window of quartz, or, better, by a piece of ice, and this is pressed upon the part to be treated. If quartz is used it requires constant attention to prevent its becoming obscured by a film of ferric oxide, which is quite opaque to ultra-violet rays. The ice renews its surface by melting, and so keeps clean and free from iron oxide deposits. This lamp is rather noisy in action. The current is obtained from Leyden jars, or from an oil-immersed con-

denser, which are fed with current from a Ruhmkorff coil, or from a high potential transformer. As a source of ultra-violet rays this instrument is good, and in the treatment of lupus it has proved itself of genuine utility, but has now been superseded by the quartz lamp of Kromayer, which is a form of Cooper Hewitt mercury vapour lamp.

100. **The Cooper Hewitt Lamp.**—This apparatus consists of a glass tube exhausted of air, and containing mercury and mercury vapour. When traversed by a current, the tube becomes filled with a brilliant light which is of a peculiar colour, and shows, if examined with a spectroscope, a line spectrum rich in green, blue, and violet lines, but very deficient in red. On this account the appearance of coloured objects, when viewed by the light of the mercury vapour lamp, is peculiar, and the face and hands present a dull livid hue. Nevertheless, the efficiency as a source of light of the mercury vapour lamp is so high that it has come into use for certain classes of illumination. The expenditure of energy is only about one-third of a watt per candle, and this contrasts favourably with the one watt per candle of the best metallic filament incandescent lamps. Not only is the illuminating power of these lamps high, but their light is also very rich in ultra-violet rays; but ordinary glass is opaque to most of these actinic radiations.

Under the name of "The Uviol Lamp," a modification of the Cooper Hewitt mercury vapour lamp has been used in medical work. A glass manufactured at Jena, and pervious to the ultra-violet rays, was used by Dr. Schott for the uviol lamp.

Since then the art of making tubes of vitrified silica has permitted the manufacture of another form of mercury vapour lamp, which emits a larger proportion of ultra-violet rays, and is known as the "Kromayer lamp." This has been found valuable in lupus, and in other skin affections. It produces a reaction in the skin in half the time required by the Finsen-Reyn lamp, it consumes far less current, and irradiates a larger area of skin at one time (Fig. 99).

101. **Sterilization of Water by Ultra-Violet Light.**—Another form of the Cooper Hewitt lamp with silica or quartz tubes has come into use for the sterilization of drinking-water, and effects this purpose very well. A lamp of this type constructed by the Westinghouse Cooper Hewitt Company will sterilize 132,000

gallons of water in twenty-four hours, and consists of a 220-volt lamp consuming 3 ampères. It is important for effective sterilization that the water be clear, as a slight turbidity prevents the

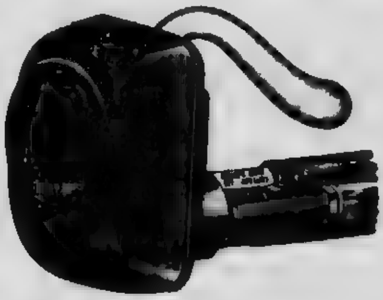


FIG. 99.—KROMAYER'S QUARTZ LAMP

full penetration of the light into the water. (See the *Lancet*, December 17 and 24, 1910, for a full account of the process, with illustration.)

CHAPTER V

HIGH POTENTIAL APPARATUS—THE RUHMKORFF COIL—TRANSFORMERS

Ruhmkorff coils—Interrupters—The mercury jet-break—Electrolytic interrupters—Spark lengths—Current waves of coils—High potential transformers—The Snook apparatus—Rectifiers of high potential currents.

102. **The Ruhmkorff Coil.**—The large induction coil has become an instrument of importance in medical practice. This is due mainly to the developments of X-ray work, but also in part to the use of currents of high frequency in medical treatment. The general principles of the induction coil have already been considered in §§ 48 and 59. Ruhmkorff coils are commonly classified in terms of the length of spark which they are capable of giving. Thus, a 12-inch coil signifies one which can give a spark 12 inches long. Twelve, eighteen, and twenty-inch coils are now in use for medical purposes.

In these large coils the primary windings are of thick copper wire in two, three, or four layers. An arrangement is used for connecting the layers in shunt or in series, in order to vary the self-induction of the primary circuit to suit the voltage of the source from which the coil is worked. The heavy iron core is finely laminated, because a solid bar of iron would become the seat of induced currents or "eddy" currents, which would heat the core and dissipate energy, and would also retard the decay of the magnetic field, upon the suddenness of which the efficiency of a coil depends so largely (§ 39).

The following data, given by Professor J. A. Fleming,* are useful as a guide to the construction of induction coils. He mentions that the primary circuit of a certain 10-inch coil consisted of 360 turns of No. 12 copper wire, and had a resistance

* Cantor Lectures, 1903. On Hertzian Wave Telegraphy.

of 0·36 of an ohm, and the secondary consisted of ten miles of No. 34 copper wire, making about 50,000 turns, and had a resistance of 6,600 ohms.

Good insulation of the secondary coil is essential. The core, after being wound with the primary wire, is enclosed in a thick tube of ebonite or of vitrified quartz, upon which the secondary wire is wound in sections, an arrangement which may be compared to a row of cotton reels placed side by side on a spindle, with the ends of the cotton joined between one reel and the next.

A 12-inch coil may have seventy or eighty of these sections arranged side by side, and separated from one another by thin discs of insulating material.

The sectional construction is adopted in order that there shall not be any great difference of potential between contiguous

FIG. 100.—PLAN OF WINDING OF A JOINTLESS SECTION COIL.

portions of the secondary coil. The sectional construction has been most developed in the "jointless section" coils of Mr. Leslie Miller. In his coils, every section consists of one flat spiral of wire, and has its corresponding insulating layer of waxed paper (Fig. 100), so that the completed secondary coil has from 700 to 1,200 single layer sections, according to its size. The extra care thus taken in the insulation of the secondary serves to reduce the number of turns of wire necessary, and thus diminishes the resistance of the coil and its impedance (§ 47), and the sparks of such a coil are consequently thicker, and the quantity of current in the discharges is increased.

The output of a coil, though commonly estimated by its simple

sparking distance in air, can be better estimated by observing the length of spark when Leyden jars are connected to its secondary terminals. The reduction of spark-length produced by the introduction of a condenser of given capacity is less the greater the magnitude of current in the discharges of the coil.

In writing on this point, Fleming has the following observations :* " A coil may give a 10-inch spark if worked alone, but on a capacity of $\frac{1}{50}$ of a microfarad (§ 25) it may not be able to give even a 5-millimetre spark. Hence in describing the value of a coil . . . it is not the least use to state the length of spark which the coil will give between pointed conductors in air, but we must know the spark-length which it will give between

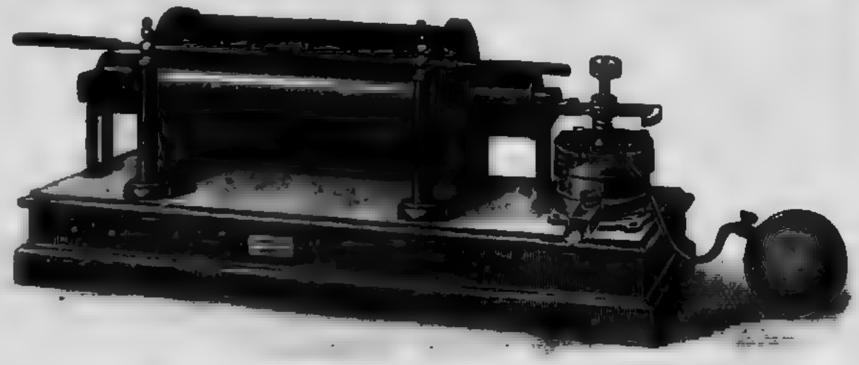


FIG. 101.—COIL FITTED WITH BÉCLÈRE GAS BREAK.

brass balls, say 1 centimetre in diameter, connected to the secondary terminals when these terminals are also connected to a stated capacity."

The appearance of the completed coil is well known (Fig. 101).

In a box below the board on which the coil is mounted, and forming part of the base of the instrument, is placed the condenser. This consists of a number of sheets of tinfoil, insulated from each other by sheets of paraffined paper. The metallic sheets are connected in two sets, the even numbers on one side being connected to one of the two supports of the contact breaker, and the odd numbers on the other side to the second support. The object of the condenser is to accelerate the rate of decay of the current in the primary circuit, as the efficiency of the coil depends upon the suddenness with which this is accomplished.

* *Op. cit.*

When the current from the battery is broken, the heat and the spark at the point of rupture tend to prolong the time during which current can pass, and make the interruption, to a certain extent, a gradual one. The condenser reduces this sparking, for the electromotive force induced in the primary wire by the rupture of the circuit is diverted into the condenser, charges it, and then discharges back through the primary winding, producing a momentary reverse current, and through it accelerating the demagnetization of the core. With very sudden interruptions the condenser ceases to be necessary.

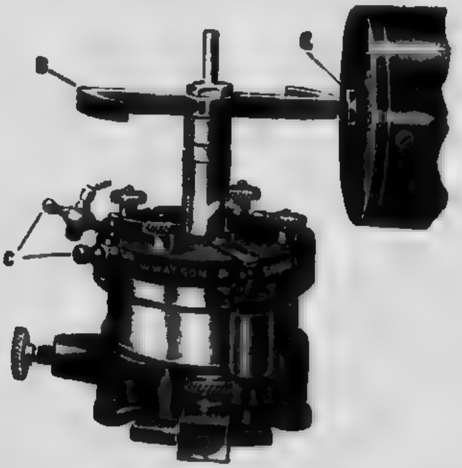


FIG. 102.—BÉCLÈRE'S GAS BREAK.
E, End of coil; *B*, Rotating iron armature; *C*, Taps for gas.

Upon the base board there is a commutator switch for reversing the direction of the current in the primary circuit. It also serves for turning the current on and off.

It is advantageous to arrange the condenser so that the whole or part can be used. If it be divided so that one-third, two-thirds, or the whole can be employed, it is sufficient for medical purposes. The same coil can be made to work to its full power, either with an accumulator of 12 volts or from the mains up to 250 volts if the primary windings and the condenser capacity can be suitably adjusted.

103. **Interrupters.**—The contact breakers of the vibrating hammer type, like those used for medical coils (§ 48), are now almost abandoned for large coils. They can only be used with

a few accumulator cells, and even so the Béclère break, shortly to be described, is far superior in results, and requires much less attention. In the preceding edition of this work the management of vibrating interrupters for large coils was considered at length, but it does not seem necessary to repeat in this edition what was there set forth. Those mechanical interrupters in which the contacts are made and broken by a plunger dipping into mercury may also be regarded as obsolete.

The rotary interrupters of to-day consist for the most part of a centrifugal pump driven by a small motor which throws a revolving jet of mercury. This jet, in its revolutions, comes periodically in contact with fixed armatures, and so makes

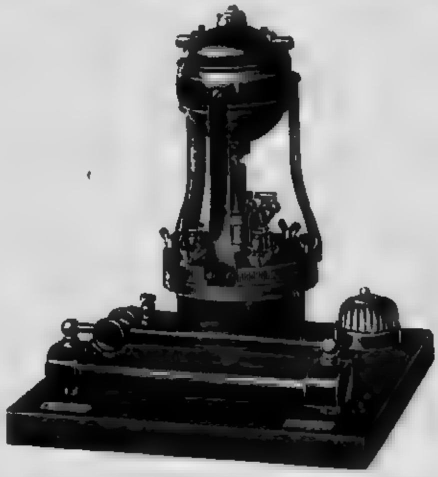


FIG. 103.—MOTOR-DRIVEN GAS BREAK.

and breaks the circuit. The action takes place in an insulating liquid such as paraffin oil or alcohol, or, in the more modern types, in a gaseous medium such as hydrogen or coal gas. The invention of this type of interrupter is attributed to Tesla, and many varieties of these mercury jet or turbine breaks exist.

Béclère's break (Fig. 102) is excellent for all but very heavy currents, and was the first form of interrupter to employ coal gas as its dielectric medium. It is of small size, and is intended to be mounted upon the base board opposite the end of the coil, and it is kept in rotation by the magnetic pull of the core, without the need for an independent motor to drive it. It is started by giving it a sharp spin, and then continues revolving until the current is cut off. It is nearly silent in action. If

preferred, it may be operated by an independent electromagnet. Béclère's break is well suited for X-ray medical treatment, and may be adapted for use on all voltages up to 250.

An improved form of gas break for heavier currents is shown in Fig. 103, and resembles Béclère's break, except that it is driven by a small motor fixed vertically above the interrupting chamber.

Fig. 104 shows the working parts of a similar interrupter, made by W. Watson and Sons. It is of massive construction, and is capable of breaking large currents satisfactorily. *A* is the iron-containing vessel, and requires four pounds of mercury in the larger size. *E* is the revolving cone, of boxwood, which is pierced with channels for the mercury, and acts as the centri-

FIG. 104.—" DREADNOUGHT " INTERRUPTER.

fugal pump. The mercury is projected from the jets *B* to strike upon the fixed armatures *C*; *H*, bearings of the motor; *K*, brushes of the motor. The stopcocks are for the admission of coal-gas.

Other rotary breaks which may be mentioned are the Mackenzie Davidson interrupter in its modern forms, and the "Sanax" interrupter. Both of these utilise mercury, and are good interrupters, but are not mercury jet breaks.

104. **Electrolytic Breaks.**—The liquid or electrolytic break of Dr. Wehnelt is a peculiar form of interrupting device, which depends for its effect upon the formation of gas and steam at the positive pole of an electrolytic cell when that pole is of small area and the current is large. A considerable amount of heat is generated, and steam is formed. This steam, with the gas liberated by electrolytic action, forms an insulating envelope

which interrupts the current. This is followed by the disappearance of the insulating layer, the current is re-established, and a fresh production of gas occurs. Thus the current is made intermittent, and the interruptions follow each other with extreme rapidity.

Wehnelt's break consists of a jar containing dilute sulphuric acid; the kathode is a lead plate, while the anode is a platinum wire enclosed in an insulating sheath, except at its extremity, and deeply submerged in the electrolyte. When a steady electromotive force, which must be of at least 24 volts, and may be as high as 150, is applied to the break, arranged in series with

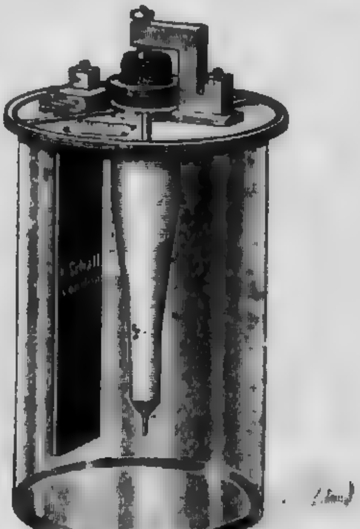


FIG. 105.—WEHNELT INTERRUPTER.

the primary circuit of a coil, the discharge through the circuit thus formed becomes intermittent, a peculiar shrill note is given out by the electrolytic cell, and streams of sparks are given off by the secondary coil. The Wehnelt break will only work on circuits of high self-induction, as, for instance, the primary circuit of a coil. The condenser is usually cut out of the circuit when a Wehnelt interrupter is used. The interruptions cease at a temperature of 90° C., and it is probable that the failure of the action when the electrolyte is hot is due to imperfect condensation of the steam.

The sheath of the anode is made of hard porcelain, and should

fit closely round the platinum. Care must be taken to make the platinum wire the anode of the cell.

A saturated solution of alum or of magnesium sulphate containing a little sulphuric acid is said to work well at low voltages. This type of interrupter has the advantage of simplicity, and, if suitably regulated, it is a useful interrupter for use with the 100-volt direct current mains. The chief objection to it is that large currents are used, and the heating effects of the large currents are troublesome if it is wished to use the interrupter for prolonged periods at a time. The current through a Wehnelt interrupter often reaches magnitudes of from 12 to 20 ampères.

The Wehnelt interrupter makes a peculiar noise when in action, but, as it requires little attention when once properly adjusted and connected, it can be placed at a distance if the noise is objected to.

It is regulated by altering the exposed surface of the platinum anode, for by increasing the surface of the platinum the current is increased, and the rapidity of the interruptions diminishes; and by reducing the exposed surface of the platinum the opposite effect is obtained. By having two or more anodes with different lengths of platinum in the vessel, the one most suited for any given tube can be connected by means of a simple switch.

The effect of self-induction in retarding the growth of current in the exciting circuit of a coil has been referred to already (§§ 47, 61), and comes into prominence in working with the Wehnelt interrupter, on account of the extreme rapidity of the interruptions.

When the primary windings are all in series the self-induction of the circuit is highest, and the spark-length which can be obtained with the Wehnelt break is short, as the current has not time to reach a high value. When the primary windings are connected in parallel the self-induction is less, and the sparks are longer. By attention to these different factors—viz., the length of the anode, the voltage of supply, and the self-induction of the primary—it is possible to obtain excellent results with the Wehnelt interrupter, and the number of sparks can be made to range from about 20 up to 1,000 per second.

105. **The Caldwell Interrupter.**—In Wehnelt's apparatus the intermittent character of the discharge is due to the formation and dissipation of gas bubbles at the anode. There is a modification of the electrolytic interrupter, which is due to Caldwell,

and independently to Simon, in which the formation of bubbles of gas is brought about at a point in the cell remote from the poles, and thereby certain advantages are secured. It consists of a cell containing dilute sulphuric acid and two plates of lead, which serve as anode and kathode. A partition of glass or porcelain separates the cell into two parts, each containing one of the metallic poles. This partition has a small hole, through which the liquids in the two portions of the cell communicate.

FIG. 106.—CALDWELL'S ELECTROLYTIC INTERRUPTER.

At this narrow opening the density of the current is very high, heating takes place, and steam is generated there and breaks the circuit; the bubbles are almost instantaneously dissipated and as quickly renewed, the rate being in part determined by the size of the holes.

In its usual form the apparatus consists of a jar containing an inner cylindrical vessel of glass, suspended so that it does not rest upon the bottom.

Connections are made by means of terminals attached to two

lead electrodes, placed in the inner and outer vessels respectively. When operating, the liquid is found to rise in the inner cylinder, which is accordingly provided with an overflow channel through which the liquid returns into the outer vessel. As both poles are of lead and of large area, there is no special need to make the connections in one particular way as required for Wehnelt's form.

With these electrolytic interrupters the appearance of the discharge of a coil is considerably altered. The sparks at the secondary terminals follow one another so rapidly as to give the appearance of torrents of sparks passing simultaneously; and with pressures approaching 100 volts, and adjustment for the highest rate of interruption, the discharge has the form of a sinuous arc of pale yellowish-green flame. For use with X-ray tubes it is best not to drive the rate of interruption too high, as few tubes will stand the strain. The higher the pressure the more rapid is the frequency of the discharge, and if it is tried to reduce the frequency by increasing the exposed area of the platinum at the anode, the current is likely to reach excessive magnitudes. To get the best work from an electrolytic break, it should be worked at as low a voltage as can be arranged to suit the tubes and coil employed.

106. **Excitation of Coils by Condenser Discharges.**—There is a mode of employing high-pressure mains for induction coils which has a theoretical interest, and that is to employ condensers which are charged from the mains and discharged through the primary coil by means of a two-way commutator. This plan, first described by Norton and Lawrence,* was developed by N. Tesla, whose apparatus is described in the *Electrical Review* † of the same year. As the discharges of a condenser through the primary of a coil are oscillatory, the discharges induced in the secondary are also oscillatory, and therefore are not exactly comparable with those produced by an induction coil excited in the ordinary way.

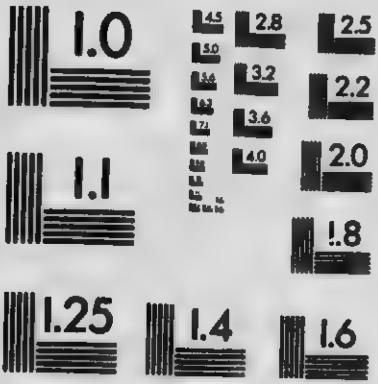
An improvement upon this idea consists in the excitation of the primary by the current charging the condensers instead of the discharging current. The advantage gained is that the charging current is a non-oscillatory one. The condensers are discharged by a short-circuiting device, the discharge current not going through the primary coil.

* *Electrical World*, New York, March 6, 1897.

† London, September 10, 1897.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



The Grisson apparatus is a contrivance for the operation of coils from the electric light mains by this method. Condensers of large capacity (100 microfarads) are momentarily connected to the mains through the primary windings of the coil. The rusn of current through the coil into the condensers comes to a natural termination when the condensers are charged to the full pressure of the mains, and if their connection with the mains is then broken, there will be no sparking at the point of interruption. The condensers are then discharged through a side circuit, after which they are ready to receive a fresh charge from the mains, sent into them through the primary of the coil as before. By means of a suitably designed commutator driven by a motor this cycle of events can be repeated in quick succession. An induction coil operated in this manner gives a magnificent discharge from its secondary terminals. The commutator is fitted with massive sections, and the condensers are aluminium cells, as these afford a means of obtaining very large capacities in an economical manner (§ 95). A switch-board is supplied with the apparatus, as the connections are somewhat complicated. The instrument has not come into general use.

Professor Ernest Wilson has also suggested a method of exciting induction coils by charging a condenser and discharging it through the primary of the coil. In his arrangement of apparatus there is a condenser, and also an electro-magnet, in which energy is first stored (§ 39), and then suddenly liberated together with the energy stored in the condenser, both discharging at once through the primary windings of the coil. The contacts needed for the charging and discharging effects are arranged by means of a special commutator driven by a small motor. It it claimed that the difficulties of the interrupter are removed by this method, and that coils can be built which are very much lighter than ordinary coils, for the same output, and require very much smaller currents to work them, owing to the efficiency of the machine; but for some reason the method has not come into use, and the apparatus is not upon the market at present.

107. **The Alternating Current Mains.**—In places supplied by direct current mains the working of large coils is a simple matter. but the direct application of the alternating mains to the excitation of coils is more complicated.

If an induction coil is connected to a source of alternating

current through an interrupter, the discharge of the secondary is irregular and unfit for use. This would not be the case if the interrupter worked in step with the periodicity of the current, so as to break the circuit at the right moment. Attempts have been made to bring about this result, and several "synchronous" interrupters have been devised.

In all devices of the kind only one speed of interruption is possible—namely, the speed which keeps time with the periodicity of the supply. In this country this ranges for the most part between 40 and 100 periods per second, which is a satisfactory rate of interruption for an induction coil. Regulation of output can be effected by the use of a series resistance to control the current or by a transformer to control the pressure.

A form of the Béclère mercury jet interrupter is made for use on alternate current circuits. It resembles the pattern used on direct circuits, but is fitted with two sets of armatures—one set for insuring synchronous rotation, and one set for supplying the primary of the coil. It is supplied by Messrs. Watson and Sons, and is driven by a separate electromagnet of laminated iron. Messrs. Gaiffe, of Paris, have also contrived a synchronous interrupter for work on alternating circuits.

Another method of adapting the alternating current mains for the operation of coils is to use the aluminium rectifier, as described in the preceding chapter (§ 95). Though the current from this apparatus is pulsatory rather than strictly continuous, it has been successfully employed, both for driving a direct current motor to actuate the interrupter and for supplying the primary circuit of the coil.

It has been noticed that there is a certain natural tendency on the part of Wehnelt's electrolytic break to transmit the pulsations in one direction more readily than in the other, and with a little care and management this form of interrupter can be used with the alternating mains. Dr. Dujon* was one of the first to point this out. He states that with a Wehnelt interrupter the discharge of his 14-inch spark coil was absolutely unidirectional, so that reversing the commutator of the coil had exactly the same effect as if he had been using a battery current. He mentions that the voltage of supply was 110, and the periodicity was 53 per second, and that the best results were given with the pressure reduced to 85 or 90 volts, with the ammeter reading

* *Archives d'Électricité Médicale*, April, 1901, p. 214.

between 4 and 10 ampères. Graduation was effected by adjusting the amount of exposed platinum in the interrupter.

Messrs. Gaiffe have constructed a special form of electrolytic break to work on alternating circuits. They advise careful adjustment of the platinum anode at the commencement, and their apparatus insures constancy of action for a considerable period of time by the following simple device: The projecting platinum pin rests at its point upon a plate of mica, which is fixed just beneath, and as the point wears away the platinum rod slips down by its own weight, and so the original length of the exposed portion is preserved. The apparatus is noisy in action, and there is a good deal of wear and tear of platinum, very much more than is the case when Wehnelt's interrupter is used with direct current.

With pressures up to 110 volts the ordinary forms of Wehnelt interrupter may be used if arranged in series with a single cell of the aluminium rectifièr, and this can easily be constructed at home by anyone with a taste for mechanical work.

The alternating mains can be used indirectly to drive a motor generator for supplying direct current (§ 91), or they can be used with an aluminium valve to charge accumulators, and these then made use of to work the coil in the ordinary way.

The choice among these methods of employing alternating mains will depend upon the worker. For least expense, the use of the aluminium valve for charging accumulators, and the working ot the coil from these is perhaps the best.

The methods of utilizing alternating mains which have just been enumerated are methods for adapting that type of current to direct current types of apparatus, and are of the nature of makeshift contrivances. The natural way of utilizing alternating circuits would seem to lie in the direction of step-up transformers capable of providing the necessary voltage as a substitute for the induction coil. This tempting short-cut has attracted investigators for some time, but the practical difficulties of the method have prevented the realization of the idea until recently. Villard, in 1899, had already advanced the matter very notably by his device of a valve tube, and by suggesting the employment of condensers of small capacity to limit the output of the transformer when this was desirable. Other obstacles of no small magnitude arose from the very high electromotive forces required, and the difficulty of constructing

a transformer which could provide such a pressure without breaking down was for a time insuperable.

The experience gained in the manufacture of large coils during recent years has prepared the way for the successful construction of transformers capable of providing pressures up to 100,000 volts, and the use of these instruments will be considered in a succeeding paragraph.

108. **The Spark-discharge of a Ruhmkorff Coil.**—The spark-discharge of a coil usually takes the form of bright crackling flashes. If the terminals are a little too widely separated for the sparks to leap across, then violet brush discharges occur from the rods of the dischargers and from the conductors which join

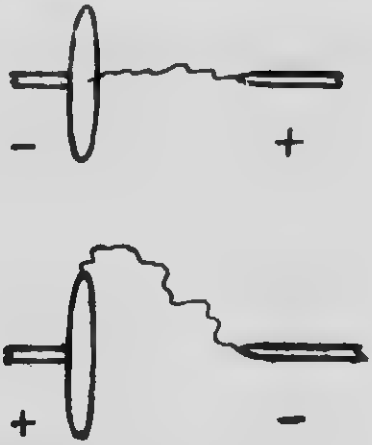


FIG. 107.—SPARK-DISCHARGES BETWEEN A DISC AND A POINT. (AFTER ARMAGNAT.)

them to the terminals of the coil. On reducing the distance separating the discharging terminals, the ordinary bright zigzag sparks make their appearance, and as the distance is further reduced the sparks gradually become thicker, and consist of a central bright part surrounded by a fainter reddish aureole. On bringing the terminals still closer together, one obtains a thick yellow curved or sinuous flame, which is hot enough to set fire to a piece of paper, a[illegible] kept in a state of upward movement by the currents of air pr[illegible]ced by its high temperature. Armagnat* points out that the sparks with aureole are really groups of sparks, the first being bright, and the others fainter and

* *La Bobine d'Induction*, par H. Armagnat, Paris, Gauthier-Villars, 1905.

redder, as they represent the residual energy of the discharge impulse, which is enabled to leap across along the line of heated air left by the first spark. The yellow thick flame discharge admits of a similar explanation, but is made up of a greater number of discharges. To obtain the longest sparks from a coil the discharges should take place between a point and a disc, and the point should be positive. Under these circumstances the sparks strike the disc upon its face, and not upon its edge. If the current be in the opposite direction, the sparks are shorter, and take a curved path, striking only upon the edge of the disc (Fig. 107). This difference of behaviour affords a simple way of recognising the polarity of the terminals of a coil.

109. **Sparking-distances at High Potentials.**—It is difficult to do more than guess at the potential difference required to produce a given length of spark in air. Many measurements have been made by different observers, but their results vary widely. The forms of the terminals between which the discharge takes place have a considerable influence upon its length, and the figures obtained in any given set of experiments seem to depend a good deal upon whether the terminals employed are plates, balls, points, or combinations of these. The uncertainties which surround the problem are quite natural, because the measurement of electromotive forces becomes increasingly difficult as the pressures rise higher and higher, and the stage at which a discharge changes from brush to spark is not always easy to determine. Fleming * writes that for sparks having lengths up to five or six centimetres we shall generally not be wrong in reckoning the voltage required to produce a spark between metal balls in air at the ordinary pressure as 3,000 volts per millimetre.

Bergonié,† in discussing the probable spark-length corresponding to 100,000 volts, sums up in favour of regarding 10 centimetres of spark-length as the equivalent of that potential difference. This would be in the ratio of 1,000 volts per millimetre, and is therefore lower than the estimate given by Fleming; but it is quite likely that at pressures of 100,000 volts and upwards the ratio of spark-length to pressure may increase more rapidly than it does at lower pressures.

* Cantor Lectures, p. 31.

† Bouchard's "Traité de Radiologie Médicale," p. 158.

110. **Current Curves of Large Coils.**– The waves of discharge of large coils are greatly dependent upon the nature of the circuit through which they are allowed to take place. When a coil discharge takes the form of sparks in air these have a very short duration, but when the discharge passes through a vacuum tube it may have the character of long waves resembling those illustrated in § 61 for small medical coils. Of those figures, the one whose contours most resemble the discharges of a large Ruhmkorff coil is Fig. 36, because the great length of the windings and the mass of the iron core of a large coil conduce to the production of long waves, which have not time to reach their close before the re-establishment of the next wave in the reverse direction. The waves at make in the secondary of a Ruhmkorff coil will also be larger, and will approximate more to those at break, in proportion as the electromotive force applied to the primary circuit is higher.

Professor Wertheim Salomonson has given a number of oscillograph tracings of the discharge curves of large coils, in a valuable paper on "The Induction Coil," published in the *Journal of the Roentgen Society* for April, 1911, and this should be consulted.

111. **The Oscilloscope.**—Gehrke has suggested the use of a special form of vacuum tube (Fig. 109) as a means of observing the wave contours of high potential discharges. It is based upon an adaptation of the fact observed by H. A. Wilson,* that in a vacuum tube the area covered by the glow upon the negative wire is proportional to the magnitude of the current through the tube. When a suitably exhausted tube is traversed by a high potential discharge the negative wire is partly covered by a violet glow, which seems to form a luminous sheath to the end of the wire, and extends along it for a certain distance. With increase of current the glow extends along the wire, and with decrease of current it becomes shorter. If the current is alternating in direction, and unequal in amount, as is the case with induction-coil discharges, then both wires show the negative glow to an unequal degree. To the eye the glow appears steady, but when viewed in a revolving mirror it is found to rise and fall in time with the interrupter, and so to trace out the contours of the wave-impulses of which the discharge of the induction coil consists.

* *Phil. Mag.*, November, 1902, p. 608.

This simple instrument is described here because it may be used to obtain valuable information as to the behaviour of induction coils. By its means the character of the discharge under different conditions can be examined. For instance, it can be used to examine the working of the interrupter of the coil, the nature of the current through an X-ray tube, or the degree of efficiency of rectifying devices. The appearances as seen in the

FIG. 108.—CURRENT CURVE OF RUHMKORFF COIL.

revolving mirror are of great beauty, and one published by Ruhmer* is given here (Fig. 108). It serves better as an oscilloscope than as an oscillograph, although photographs can be taken by the device of driving the mirror synchronously, as has been shown by Ruhmer. In judging the appearances observed in the mirror, it is necessary to remember that the

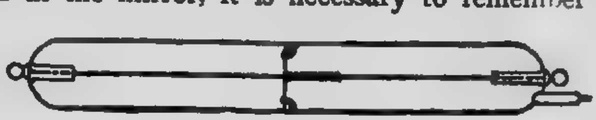


FIG. 109.—VACUUM TUBE OSCILLOGRAPH.

glow upon the wire is not a mathematical line, but has a certain thickness, and, in addition, that it has a peculiar "test-tube" shape, for which reasons the curves seen in the mirror present a certain degree of distortion, which, however, is not sufficient to interfere with the value of the apparatus for qualitative purposes. This form of Gehrke's tube is 35 centimetres long and 4 in diameter, with two rigid nickel wires arranged axially.

* *Elektrotechnische Zeitschrift*, February 9, 1905.

The interval separating their ends is very short—viz., about 2 millimetres—and a disc of thin porcelain or mica is fixed at this point. It is pierced by a small hole, which corresponds with the ends of the electrodes. The vacuum is about 6 millimetres of mercury.

112. **High Potential Transformers.**—The great convenience attending the working of large coils directly from the continuous current mains, and the difficulties of doing the same thing in places supplied by alternating current, have led to many attempts to devise a satisfactory method of utilizing alternating currents in a similar way for the production of very high potentials. Further, the improvements in the manufacture of large coils, which have resulted from the general demand for that form of apparatus, has led to similar improvements in the construction of high potential transformers, and these can now be obtained to give pressures of 100,000 volts. Several makers of electrical apparatus have turned their attention to the adaptation of high-potential transformers for medical applications. Messrs. Gaiffe were the first constructors to introduce high-pressure transformers for these purposes, and for several years they have manufactured a transformer equipment specially arranged for X-ray and high-frequency work. In that apparatus the high-pressure side of the step-up transformer is shunted by condensers, called guard condensers. It is probable that their action may be partly protective and partly of the nature of a resonance device. Each lead then passes through an electrolytic cell of special construction, and then to another pair of condensers. On the further sides of these condensers are the discharging terminals, and when unidirectional current is required a pair of valve tubes are arranged across them, so as to carry the current in one direction and resist its passage in the other. J. Koch, in Germany, also made use of a transformer, and combined with it a revolving commutator to rectify the currents synchronously produced.

All high-pressure transformers are somewhat dangerous, and they should be enclosed in locked cabinets. The device of an automatic switch which cuts off the current when the doors of the cabinet are opened is a convenient safety arrangement. These high-pressure transformers give out streams of sparks, which closely resemble the sparks from a large induction coil. Some of those who have worked with a transformer apparatus

find the results so satisfactory that they advocate the use of a transformer in place of the Ruhmkorff coil even in places supplied by direct current, although this involves the use of an additional piece of apparatus—viz., a motor transformer—for converting the direct into alternating current before it can be supplied to the step-up transformer. On the other hand, this use of a motor transformer provides the best kind of synchronous arrangement for rectifying the high-pressure current, and converting it into a unidirectional current suitable for X-ray work. The best known and most successful of these machines is known as the

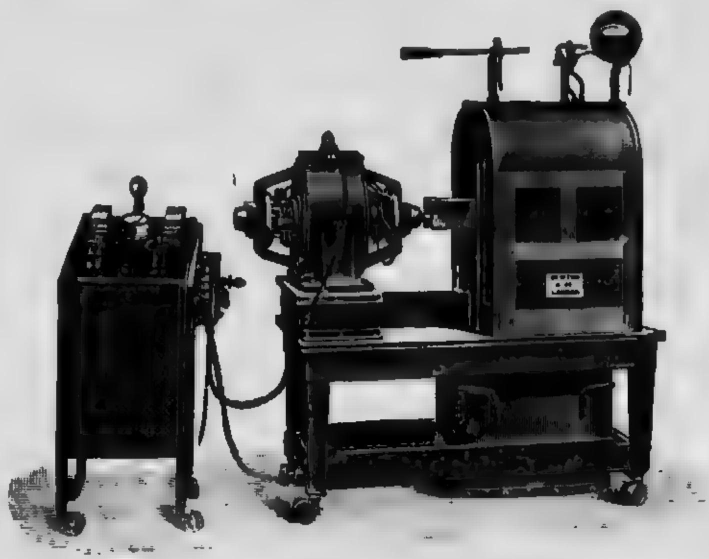


FIG. 110.—THE SNOOK APPARATUS.

" Snook " apparatus, after H. C. Snook, of Philadelphia, and is shown in Fig. 110. It is made in this country by Messrs. Newton and Co.

It consists of a motor generator driven from the direct current mains, and supplying alternating current to a step-up transformer. Attached to the axle of the motor generator is a commutator, which consequently moves with the motor generator, and therefore cannot get out of step ; and this insures the delivery to the outside circuit of perfectly unidirectional current at a pressure of some 70.000 to 100.000 volts. The high-pressure transformer is enclosed in a tank of oil, and the whole apparatus is enclosed in a large cabinet.

When intended for use from alternating mains, the rectifying device is operated by a small synchronous motor, but in practice it has been found that this does not work so satisfactorily as is the case when the commutator is actually driven by the axle of the alternating current generator.

113. **Rectifiers for High Potential Currents.**—In the last paragraph the use of rectifiers for high-pressure alternating currents has been referred to.

Although the principle of rectification has its most important applications in the case of transformers, it may also be useful in some cases with induction coils. The current of a coil is alternating in direction, though the electromotive forces are greater in one direction than they are in the other, as we have already seen. In the case of the coil a spark-gap has long been used when unidirectional impulses are required, because the length

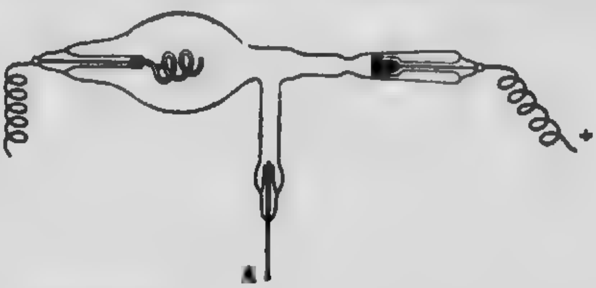


FIG. 111.—VALVE TUBE OF VILLARD WITH VACUUM REGULATOR (A).

of the spark-gap can be so adjusted as to present an obstacle to the waves of low electromotive force, but not to those of greater strength in the reverse direction. This sifting action of a spark-gap is much enhanced if the terminals of the gap are made in the shape of a plate and a point. Current crosses such a gap best when the point is positive, as we have seen in a preceding paragraph. For X-ray purposes the use of a valve-tube rectifier arranged in series in the secondary circuit of an induction coil improves the working.

In 1899 M. Villard invented an ingenious rectifying device or valve tube for correcting this difficulty. It consists of a vacuum tube in which one terminal is enclosed in a narrowly-constricted portion of the tube, while the other is suspended freely in a wide portion (Fig. 111). A tube of this kind will transmit current easily when the helix is the kathode ; but when the current is in

the opposite direction it transmits little or none. These valve tubes can be used in either of two ways—viz., arranged in series with the apparatus so as to arrest the impulses tending to traverse it in the one direction, while providing a free passage for the impulses in the other; or else being placed in shunt to the

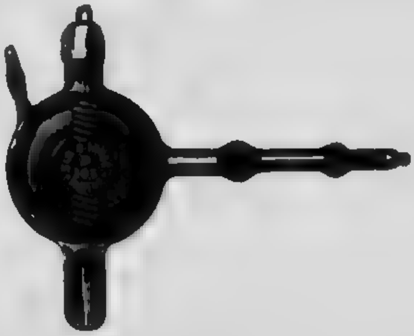


FIG. 112.—LODGE'S VALVE TUBE.

apparatus so as to carry off the wrong impulses, while resisting the others, and so compelling them to traverse the desired path.

An improved form of Villard's valve has been designed by Sir Oliver Lodge (Fig. 112), and is now superseding it. It rectifies well, is of robust construction, and will carry larger currents.

J. Koch has also suggested another form of valve tube, but those previously mentioned are the most efficient.

Reference should here be made to the rectification of current

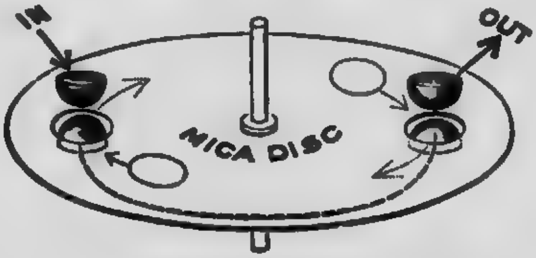


FIG. 113.—REVOLVING DISC RECTIFIER.

by means of a commutator revolving in synchronism with the interrupter or the alternating generator. In some of these devices a metal arm carrying a pair of knobs revolves in synchronism in such a way that at the proper moment the arm bridges a gap in the circuit of utilization, and so permits the

passage of the current ; but when the direction of the current is wrong, the moving arm has passed away from its former position, and the circuit is therefore broken.

The same result is obtained by the periodical breaking of the circuit by the interposition of a non-conducting layer. Fig. 113 shows a disc of mica pierced by two holes and rotating between two pairs of knobs, along which the current is to pass, as indicated by the broken line. When the current has changed its direction, the holes in the disc have passed away from their previous

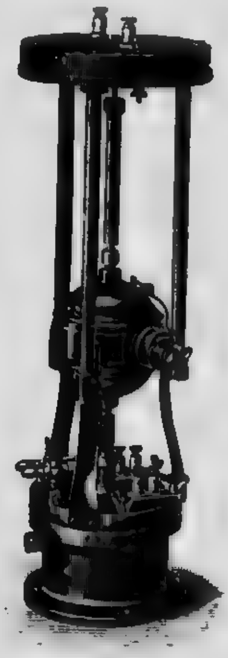


FIG. 114.—MERCURY INTERRUPTER FITTED WITH MICA DISC RECTIFIER.

position, and the plate of mica prevents the passage of any current until the proper moment, when the holes are again in position to allow the spark to leap across the intervals between the pairs of knobs.

Fig. 114 shows the mica disc valve arranged on a prolongation of the axle of the motor which works the interrupter. One terminal of the rectifier is joined to one terminal of the coil, and the other terminal of the rectifier leads to the outside circuit. Once properly adjusted, this rectifier needs no attention.

CHAPTER VI

ELECTRICITY OF HIGH POTENTIAL—STATICAL MACHINES

Historical—Description of instruments—The Holtz machine—Wimshurst's machine—Conductors and electrodes—Treatment by charging—The static breeze—Treatment by sparks—The "static induced current"—The Leyden jar—Morton's method.

114. **Electrostatic Machines.**—The use of electrostatic machines for medical purposes is of historic interest, for it dates back to the dawn of the science of electricity.

De Haen (1745), Jallabert (1748), and the Abbé Nollet (1749), were the first to apply statical electricity to medicine.

In 1758 Benjamin Franklin relates that in consequence of the cures reported to have been made in Italy and Germany, a number of paralytics were brought to him for treatment from various parts of Pennsylvania and the neighbouring provinces.

In 1759 the Rev. John Wesley, the famous divine, collected a number of cases in which electricity had been tried, and published a treatise entitled "The Desideratum, or Electricity made Plain and Useful, by a Lover of Mankind and Common Sense." In this are given the details of a vast number of cases treated by electricity. Among them he mentions that electricity accelerates the passage of calculi through the ureters. He also relieved tertian and quartan fevers and hysteria.

In 1777 Cavallo published in London a complete treatise on electricity in theory and practice, with original experiments. It included general remarks relating to Medical Electricity.

The first form of electrical machine was a large sulphur ball, which was excited by the friction of one hand as it was revolved by the other. It was made by Otto von Guericke, of Magdeburg, in 1672. Subsequently resin, and then a glass cylinder, were used, instead of the sulphur ball, and in 1740 horsehair cushions covered with silk were used instead of the hands for producing the friction.

Some interesting reproductions of old figures of early electrical

machines are given by Dr. Mount Bleyer of New York in Bigelow's "System of Electro-Therapeutics."

In 1760 Ramsden substituted a circular glass plate for the cylinder, and his apparatus was, until recently, in common use.

In modern machines induction is utilized for producing the electrical separation, and on this account they are often known as influence or induction machines. In 1865 Holtz of Berlin invented a machine which, when once charged, would continue to produce electrical separation by induction. It proved to be far superior to the older frictional machines, and quickly

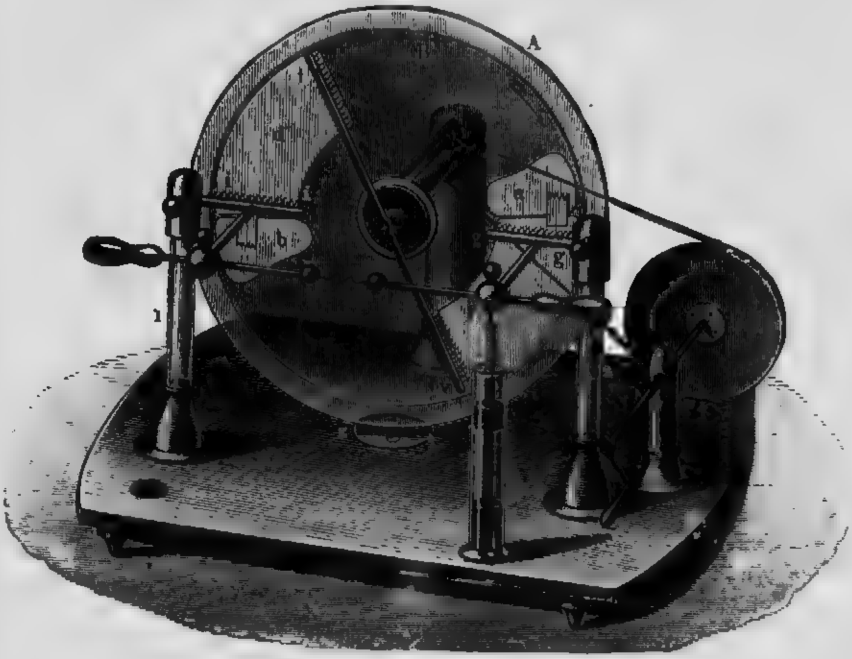


FIG. 115.—HOLTZ MACHINE.

supplanted them, in spite of certain drawbacks. In its original form it required to be excited from an outside source before it could begin to work, it was liable to lose its excitation if worked upon open circuit, and it had a tendency to reverse its polarity during action; but from its good qualities it has been made the object of much attention, and has been much improved by the instrument makers of the United States, where the Holtz machine is in general use for therapeutic purposes.

115. **The Holtz Machine.**—In its simplest form it consists of two plates of glass, A, B (Fig. 115), one having a diameter

slightly greater than the other. The larger plate is fixed, but the smaller one rotates. The plates are close together, but do not touch. In the fixed plate are two openings or "windows," *a*, *b*, diametrically opposite to each other. Two pieces of paper called "field plates" are glued on to the fixed plate, one above the window on the left side, and one below the window on the right. They are on the surface of the plate away from the revolving one. A tongue from each of these pieces of paper protrudes through each aperture, and nearly touches the revolving plate. The plate is rotated in an opposite direction to that in which the tongues point. Two metallic combs, *g*, *i*, supported by brass rods with knobs, *f*, and mounted on glass supports, form the prime conductor. Two smaller brass rods, with ebonite handles and knobs, act as discharging electrodes, by means of which the length of spark can be regulated. The rod, *t v*, is called the neutralizing rod, and is said to make the machine less likely to reverse its polarity when working. Before starting the machine, one of the field plates must be charged from an outside source, and the knobs of the discharging rods are to be brought together. The movable plate is then rotated rapidly, and a series of sparks will pass between the electrodes.

In the modern machines used in electro-therapeutics there are many modifications in details. First, the machine has four, six, or eight pairs of plates, and is enclosed in an air-tight case. The fixed plates are no longer circular, with windows and a hole for the axle, but for the sake of simplicity of manufacture they are oblong, and are held in place by grooves in the framework of the case, and each is made in two pieces which do not quite touch each other, and so leave room for the axle to revolve between them. The "field plates" of paper are glued to the fixed plates on the side which faces the rotating plate or near side, instead of being on the opposite or far side. This prevents the reversals of polarity during action, which occurred with the original Holtz machine, by preventing the formation of an accumulated charge of opposite sign on the near side of the fixed plate, as used to be the case when the field plate was attached on the far side.

Machines for electro-therapeutics usually have revolving plates 30 inches in diameter, and are generally driven by an electric motor. For providing the initial charge which is required to

excite the action of the machine, a small Wimshurst or Voss machine is fitted in the corner of the case of the instrument.

116. **The Voss or Toepler Machine** is also used directly as a medical static machine. It is more nearly a self-exciting machine than the Holtz, but, like that form, it is less sure in its action than the Wimshurst machine.

FIG. 116.—HOLTZ MACHINE FOR MEDICAL USE.

The Voss machine resembles the Holtz in a general way, but the moving plates carry a few sectors, and these in their rotation touch a pair of brushes which are carried by two bent arms which connect with the field plates and so convey charges from the moving plate to the armature of the fixed field plates.

The Wagener mica plate machine is a modified Voss machine, in which the moving plates are made of a compound of mica

and shellac. They are light, and can be safely driven at a high speed.

117. **The Wimshurst Machine.**—The Wimshurst machine has the advantage over the Holtz that it is self-exciting, and its polarity will not reverse under ordinary circumstances while it is in action. It consists of two circular glass discs (or any even number up to twelve), mounted in pairs upon a fixed horizontal spindle in such a way that they rotate in opposite directions at

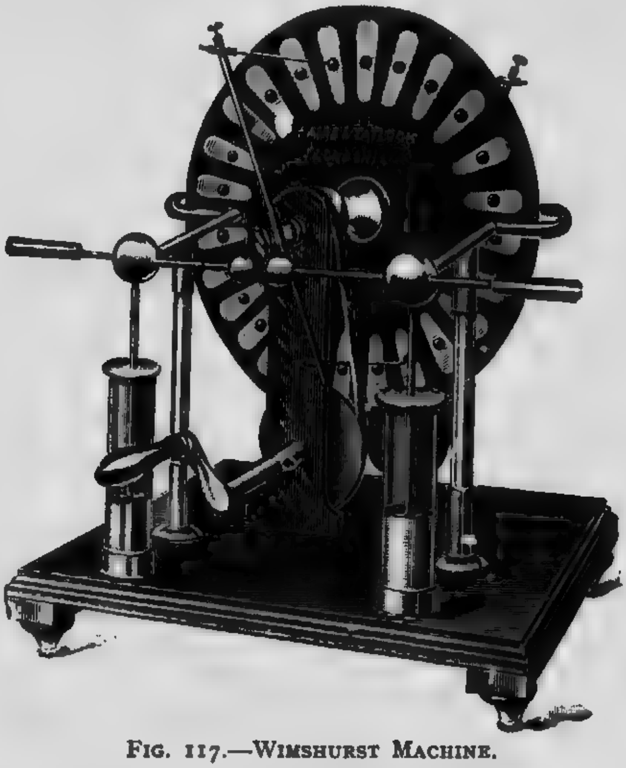


FIG. 117.—WIMSHURST MACHINE.

a distance apart of not more than a fraction of an inch. Each disc is attached to the end of a hollow boss of wood, or of metal, upon which a small pulley is fixed. The pulleys are driven by a cord or belt from larger pulleys attached to a spindle below the machine, and rotated by a winch handle or by a motor, the difference in the direction of rotation of the discs being obtained by crossing the alternate belts.

Both discs are well varnished, and attached to the outer surface of each there are radial sector-shaped plates of tin-foil or

thin brass disposed around the discs at equal angular distances. These sectors are not essential to the action of the machine, but they make it more easily self-exciting.

Twice in each revolution the two sectors situated on the same diameter of each disc are momentarily placed in metallic connection with one another by a pair of fixed wire brushes attached to the ends of a curved rod, called the neutralizing rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate, the sector-shaped plates just grazing the tips of the brushes as they pass them.

The position of the two pairs of brushes with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angle; and there is one position of maximum efficiency. This position in the machine appears to be when the brushes touch the discs on diameters situated about 75 degrees from the collecting combs, and 30 degrees from one another.

The fixed conductors consist of two forks furnished with collecting combs directed towards one anotner, and towards the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, being along the horizontal diameter of the disc. To these fixed conductors are attached the terminal electrodes, whose distance apart can be varied. Leyden jars are usually fitted to the machine by the makers, but these must admit of their outer coatings being disconnected, if the machine is to be used for treating patients.

The machine is very efficient and perfectly self-exciting, provided there are sufficient sectors, generally requiring neither friction nor outside electrification to start it, and this is one of the most remarkable features of the apparatus, for under ordinary conditions the machine works at its full power after the second or third revolution of the handle. It has been suggested that the initial charge is obtained from the friction of the air, and that chiefly between the plates, but nothing certain is known about it.

The mode of action of a Wimshurst's influence machine is not easy to explain in a few words. The following extract from a paper by Mr. Pidgeon* gives a general notion of the occurrences which take place when the machine is in action: "If we

* *Phil. Mag.*, September, 1893.

follow the action of any single sector on a disc of one of these machines, we find it goes through the following electrical changes. Suppose it to be just leaving the positive collector, it comes into a strong positive field produced by the other disc, and while in this field is earthed by the first neutralizing brush, and becomes charged negatively."

The Wimshurst machine is at its best when the resistance of

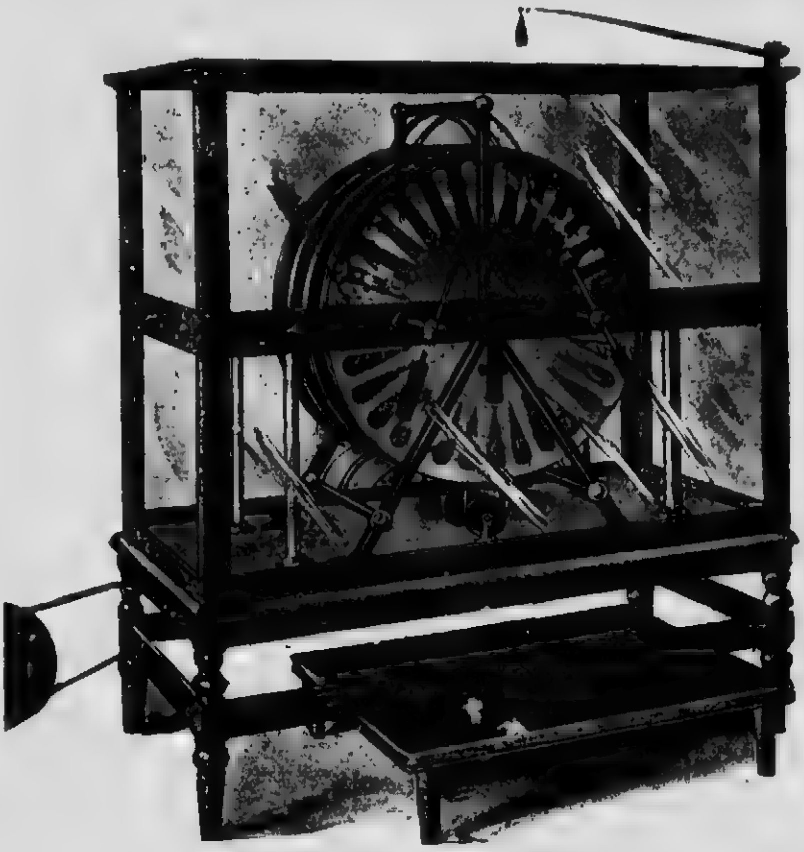


FIG. 118.—WIMSHURST MACHINE.

the discharging circuit is very high, and the opposite condition of a free discharge in the outside circuit suits the Holtz type of machine best.

A Wimshurst machine for therapeutic work should have eight plates of 30 or 36 inches diameter. Fig. 118 shows a machine built for the writer. This machine, without any Leyden jars, gives streams of sparks 10 inches long. It is enclosed in a roomy

case to prevent waste by leakage from the machine to the case, and to protect it from damp and from dust. It runs silently and smoothly, and has not failed on any occasion. It is driven by a ¼-horse electric motor.

Messrs. Watson and Sons, of High Holborn, have taken up the manufacture of the type of machine shown in Fig. 118, and are prepared to supply an outfit with all accessories complete.

A modification of the Wimshurst machine is made with ebonite plates, which may safely be driven at a very high speed. There is, however, a grave objection to the use of ebonite plates in expensive machines, because of their tendency to deterioration through a chemical change of their surface, by which they lose their insulating properties; moreover, plates of ebonite are difficult to keep true, as they have a tendency to bend and buckle.

M. Gaiffe of Paris has lately introduced a sectorless Wimshurst machine, with a simple attachment of the ebonite plates which makes it very easy to remove them for cleaning. He proposes by this means to do away with the need for a case, and so to cheapen its cost and make it more accessible for purposes of adjustment. The plates are 22 inches in diameter, and they can be run safely at the high speed of 1,000 revolutions per minute. There are no sectors, and external excitation is usually required to start it into action, but when once started the output is large.

It is probable that the labour of keeping such a machine clean would more than counterbalance the supposed advantages of saving the cost of a case. In the smoky air of towns a machine in action attracts soot and dust very much.

A good type of static machine with ebonite plates is made by Mr. A. E. Dean.* It can be fitted with sectors if required, and if this addition be made to one pair of the plates it is probable that the machine will be more easy to start into action. Some electric lamps are fitted to the stand of the instrument, in order to keep the atmosphere warm and dry around the plates (Fig. 119).

It has been proposed to enclose the Wimshurst machine in a strong metal case, and to work it under an air-pressure of several atmospheres, in order to reduce the internal leakage by brush discharges, which is one cause of the inefficiency of static machines.

In a machine of this kind, designed and made by Mr. F.

* Leigh Place, Baldwin's Gardens.

Tudsbury, the case is made of stout metal, and it can be filled with compressed air by means of a bicycle-pump. Carbonic acid gas may also be used instead of atmospheric air, and a supply can be kept in readiness in a steel gas-bottle. The advantages of this gas over ordinary compressed air consists in the fact that it does not yield ozone under the influence of brush discharges, and the destructive effect of ozone upon

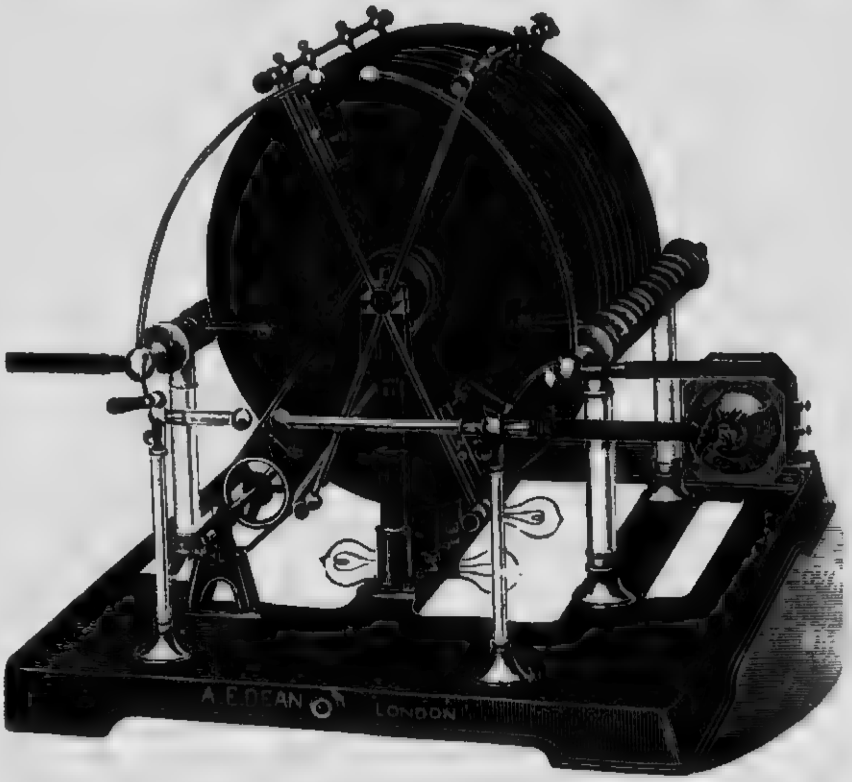


FIG. 119.—THE DEAN STATIC MACHINE.

ebonite can thus be avoided. At present this machine is only made in small sizes, and even so is very heavy, owing to the weight of the metal case.

118. **Static Effects from the Ruhmkorff Coil.**—An apparatus for obtaining from an induction coil discharges like that of the static machine has been designed by the Cavendish Electrical Company, 130, Great Portland Street. It makes use of the rectifying effect of a valve tube (§ 113) to obtain unidirectional current, and reduces the force of the discharges by a column of

badly-conducting liquid in a glass tube. The apparatus yields effects very similar to those of a static machine.

119. **Medical Applications.**—In any form of machine adopted the requirements are the same—namely, the machine must be large enough, and built to stand hard work. It should be enclosed in an air-tight case, and pads of indiarubber under the feet of the machine may be used to lessen vibration in working. The progress made in statical treatment in the last few years is largely due to the work done in the United States, where the Holtz machine is now employed widely by medical practitioners for therapeutic purposes and for X-ray work. In country places

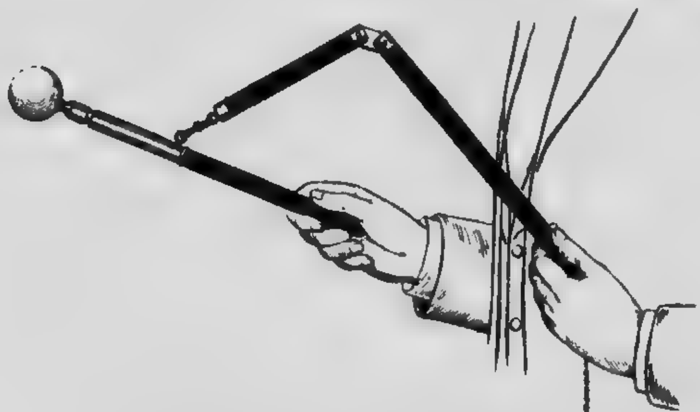


FIG. 120.—DR. MONELL'S ELECTRODE HOLDER.

the occasional X-ray work of general practice is admirably served by a static machine.

Dr. Monell, of Brooklyn, the author of "A Manual of Statical Electricity in X-ray and Therapeutic Uses," recommends that the patient be insulated upon a platform with glass legs, and connected to one pole of the machine; the electrodes are to be connected to earth, and the second pole of the machine is also earthed. The advantage of this mode of procedure is that the instruments handled by the operator are at zero potential, which makes it unnecessary to use any insulating device to guard against shocks. The earthing of the electrodes is arranged by a light metal chain connected at one end to a gas or water pipe in the building, and fitted at the other end with a handle shaped like a flail, to which the electrodes are hung. This handle, or "electrode holder" (Fig. 120), of Dr. Monell is held in the left hand close to the body,

and supports the weight of the electrodes very much as a crane supports a weight. Thus, one hand is used to direct the electrode, while the other supports the weight of it.

For a means of changing the polarity of the insulated platform a solid ebonite rod with brass terminal knobs is fixed in a wooden clamp between the dischargers of the machine (Fig. 121). The upper knob is for the earth connection, the lower is for the connection to the platform. In this way either pole of the machine can be put to earth while the other is connected to the platform.

The accessories which are used in applying treatment with the static machine are as follows: A platform with glass

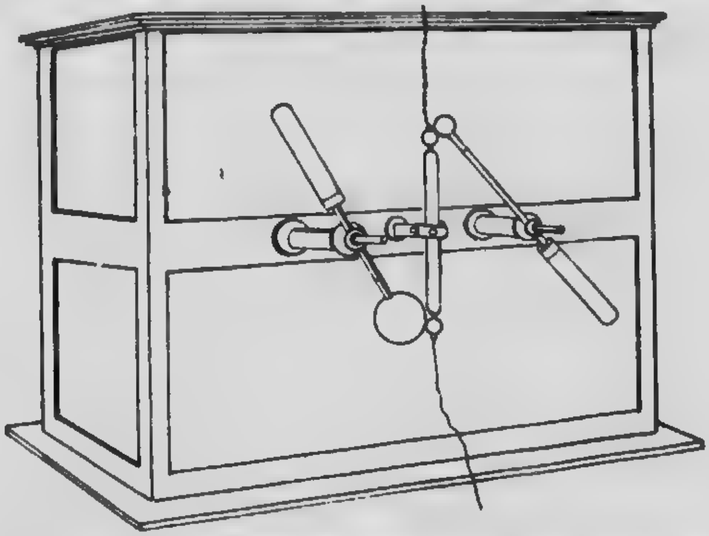


FIG. 121.—FRONT OF CASE, SHOWING EBONITE ROD WITH CONNECTIONS TO EARTH ABOVE AND TO PLATFORM BELOW AND ARRANGEMENT OF POLES.

legs, chains for earthing conductors, a single-point electrode, a multiple-point electrode, a brass-ball electrode, a brass roller, and a Monell's handle for holding these; also a swinging brass rod carrying a wire tassel, which is best attached to the case of the machine as shown in Fig. 118. These, with a sheet of brass for a footplate, and a connecting rod or wire to connect the platform to the machine, are enough for most purposes. There are other electrodes for special purposes, and it may be of advantage to have Leyden jars for use in certain cases. These are often fitted to the machine. Their applications will be considered in a later paragraph.

Hitherto the demand in Great Britain for static machines adapted to medical purposes has been a small one.

120. **The Insulated Platform.**—This should be strongly made and well designed. A bad platform may reduce the efficiency of the treatment by one-half, through losses of charge from leakage. To reduce these losses as far as possible, the platform must be made with all corners and edges carefully rounded off and made smooth; the glass legs should be at least 10 inches long, and 12 inches is even better. There should be a rounded beading or edging to the platform, to prevent the chair or stool

FIG. 122.—ELECTRODES FOR STATICAL TREATMENT.

from slipping off through any movements of the patient. The dimensions recommended by Monell are 42 inches by 27. The platform and the glass legs must be strong enough to support the weight of the heaviest patient. Owing to the size of the platform, it is useful that the case of the machine shall be so built as to permit of the platform being pushed underneath it when not in use, as otherwise the platform takes up a great deal of floor space.

121. **Electrodes.**—Fig. 122 shows the four chief electrodes—namely, the single point, the multiple point, the knob or ball

electrode, and the roller. The eye at the side of the electrode is for attachment to the Monell handle, while the eye at the end is for hanging up the electrodes upon hooks when they are not in use. A stand with combined ball and point electrode is useful in certain applications, as it can be raised and lowered to bring the point into any desired position. The knob at the other extremity reduces loss by leakage, and increases the effectiveness of the point.

The single point electrode is used for giving the static breeze, and Bordier recommends a blunt point with an angle of 90 degrees as most effective. The multiple point is for the same purpose, its effect being rather stronger. The ball electrode is 3 inches in diameter, and is used for administering sparks. The roller also gives spark discharges, but in a special way. It is used by rolling it over the surface (clothed) of the patient. When this is done, showers of very short sparks are given off, of a length equal to the thickness of the layer of clothing between the roller and the skin. These short sparks produce a very strong sensory effect, and the roller electrode must therefore be used only with very rapid movements, otherwise the sensation becomes unbearable. It is a valuable electrode in certain conditions, and its effects are highly stimulating.

122. **Distinction of Poles.**—To test the polarity of the machine, take the earthed point electrode in the hand, and present it to a knob of the machine in action. Gradually bringing it nearer and nearer, as it approaches the positive knob a star of light will appear on the point, even at a distance of several inches, and this star of light will remain without much alteration until the point is brought up almost into contact with the knob, when small sparks pass. If approached to the negative pole in the same way, the discharge takes the form of a visible brush or spark when the point is still at a distance of 2 or 3 inches from the knob. It is easy to recognise these differences in the discharge to the point, and from them to know which pole is the positive and which the negative.

123. **Simple Charging.**—The patient is to be seated on a stool or chair on the insulated platform, and the foot-plate connected with the machine by a wire or chain, or brass crook. On the brass plate is placed a footstool, and on that the patient rests his feet. The machine is then set in action and its polarity tested. Then bring the positive pole into contact with the conductor to

the platform, and take the other one to the earth connection and start the machine. The patient is then charged positively. The presence of nails in the seat of the stool is undesirable.

As soon as the patient becomes charged he feels certain sensations. The hair begins to move, and on the scalp and face, and to a less degree on other parts, he feels as if lightly touched by gossamer or cobwebs. If any piece of furniture or other object or person be near, he may feel a breeze blowing towards him from it. If the platform is too near the machine, this breeze will be particularly felt from the direction of the grounded pole of the machine. The platform, therefore, should be 2 feet or more away from the side of the machine and from any furniture or the walls of the room, and the friends of the patient must be warned not to touch or hand anything to the patient, otherwise a spark will pass between them, and both will receive a shock.

Simple charging (positive or negative) may be continued for fifteen minutes or longer. Its effects are agreeable and tonic. It is the mildest form of statical treatment, and is usually given in combination with a brush discharge to the head or spine or both; it is also a necessary part of all statical treatment administered to a patient on the insulated platform. Usually the patient is charged positively. It has been said that the negative charge produces feelings of prostration, while the positive produces invigoration. This is probably incorrect—at least, it is not supported by everyday experience—though the idea serves to decide that when simple charging is desired the positive charge shall be preferred.

124. **The Morton Wave Current.**—In addition to the continuous electrification described in the last paragraph, there is a method of alternately charging and discharging the patient which is recommended by recent writers as a more energetic tonic treatment than the simple charging. It is often known as "The Morton wave current," and Monell has given it the name of "Potential Alternation." It is applied as follows: While the patient is being charged, the knob or ball electrode, grounded as usual, is brought near to the knob of the machine from which the patient is being charged. As it approaches, a sharp cracking spark passes, and the patient is discharged, to be immediately charged again from the machine and again discharged in the same way as before. The chargings and dischargings follow each other with a rapidity which depends upon the activity of the

machine and the width of the gap across which the spark must leap. The patient's hair can be seen to oscillate in time with the sparks, especially if the head breeze electrode be in position during the application. This method has the disadvantage that the stream of sparks makes a distracting noise which some patients cannot endure. Other patients do not mind the noise so much and find the application not unpleasant.

125. **The Brush Discharge or Breeze.**—If when the patient is charged on the platform a grounded point electrode is presented to him, he feels the sensation of a wind blowing towards him from the point; this is the electric breeze, or wind, or *souffle électrique*. It can be felt when the point is a yard away, but becomes much more strongly felt when the point is brought nearer, right up to the distance at which the discharge changes from the silent discharge to that of sparks. The safe distance varies according to the polarity of the patient. When he is positive, the grounded point can be brought much closer without sparking than when he is negative. The breeze which is felt as a cool wind upon the bare skin acquires a pricking hot character when directed upon covered parts, and the prickly sensation is greater when the patient is positively charged. Usually, therefore, the patient is charged positively, except when the mildest form of breeze is desired, as may be the case with timid or unaccustomed patients. The breeze produces a very grateful sensation when applied to the scalp and to the nape of the neck, and it is usual to arrange a special electrode for this head breeze by means of a hinged arm supporting a wire tuft or tassel, or a crown-shaped metallic arrangement. In Fig. 118 this is shown as a rod projecting from out one top corner of the case, and has a universal joint enabling it to be swung out or in and raised or lowered to bring it into place over the patient's head as he sits upon the platform. The scalp can also be "breezed" mildly by the point electrode held in the operator's hand.

The breeze is called the "negative breeze" when the patient is positive, and *vice versa*. The breeze can be varied in strength by varying the distance between the point and the patient's surface. When the strongest effects are desired, the point (single or multiple) is brought as close as is possible without sparking; the effect then is something like a douche of hot water, and may be so strong as to be unpleasant, especially if kept acting for long upon one spot. It is more easily borne if the

electrode is kept moving over the surface. The effect of a strong negative breeze upon the spinal region and the back is very invigorating, and it leaves a warm glow or after-effect. As the effect of clothing in modifying the sensations of the breeze discharge is so marked, it is occasionally useful to vary the thickness of clothing to suit the requirements of the case, and this can best be done by using a woollen shawl, which may be thrown over the patient at any part where the strongest stimulation is desired. All the fabrics used in clothing do not behave alike in modifying the sensations produced by the breeze, for occasionally the corsets (or the back of the waistcoat in the case of male patients) may prevent the breeze from penetrating satisfactorily. It is not often, however, that difficulties arise, and when they do it is generally possible to overcome them. Occasionally the metal parts of the stays, or buckles, or hairpins, or fine gold chains worn round the neck, or a steel key-chain in the side pocket will cause some pricking or discomfort at the wrong place, and must be attended to.

When the patient's skin and underclothing are moist with perspiration the effect of the breeze is greatly diminished, and in warm weather patients must be told not to walk hurriedly to keep their appointments; occasionally in very close summer weather the roller must be used instead of the point.

The breeze may be modified and strengthened by interrupting the charge as it passes from the machine to the patient; this is easily done by moving the conductor of the machine a little distance from the knob which leads the current to the platform.

The effect of the breeze is to produce definite cutaneous sensory impressions which can be adjusted so as to be either soothing or highly stimulating. It raises the blood-pressure, and in many cases of headache, in anæmic subjects with low blood-pressure, the effect is quite magical—that is to say, the breeze applied for five or ten minutes will remove the pain entirely. In addition to this local effect, which is often very valuable, there is a general comforting effect from the breeze applied to the head, the nape, and the spine, for which patients are grateful. The sensations may be compared to those of a fine hot water douche.

126. **Treatment by Sparks.** — For giving sparks the knob electrode is used, and as the sensation of a spark is disagreeable they must be given neatly so as to avoid all unnecessary discomfort to the patient. The important point is to give only

one spark at a time and not a volley. To do this the knob, earthed as usual, is swept quickly in a curve past the place at which the spark is aimed, so that it is away again and out of range before a second spark can follow the first. With a little practice this becomes easy. The sparks may be repeated as often as it is judged to be necessary. Long sparks must not be directed upon bony prominences, nor upon any place where the bone is thinly covered with soft tissues, nor upon the face, the female breast, or other sensitive parts. The length of the spark can be decreased by partially discharging the patient before giving the spark, and this is easily done by the operator placing his foot upon the edge of the platform, and so causing part of its charge to leak away. Sparks from a knob are more severe than those from the point or roller; the impression produced by a single well-directed spark is just that of a blow, the sensation depending mainly upon the sudden muscular contraction caused by the spark. It is as well to give the patient notice before each spark. With ladies the sparks, if used at all, must be weakened in the manner indicated.

127. **The Roller: Electric Frictions.**—When the roller is rolled over a clothed surface, showers of short stinging sparks pass off from it to the patient, and the thicker the layer of clothing under the roller the sharper are the sensations. Thus they can be made stronger by a woollen shawl thrown over the clothing, and milder by the removal of an outer garment. The sensation is severe, and leaves a tingling glow behind it which persists for some time. To use the roller it is best first to discharge the patient by means of the foot on the platform, and then quickly to put the roller in place, withdrawing the foot and sweeping the electrode over the surface immediately. All should be done in a few seconds, or the patient may protest. As in the case of long sparks, patients like to receive notice of the roller, if it is to be applied to any part of the back where they cannot see it coming.

128. **The Leyden Jar.**—This apparatus (§ 13) was discovered in 1749. Owing to the arrangement of its coatings it has a large capacity, and in its discharge there is a larger "current" than in the spark from the prime conductor of a machine as ordinarily constructed.

This makes itself felt as a more severe shock when the discharge takes place through any portion of the body. The

Leyden jar is therefore used when it is desired that the patient shall receive a sudden shock.

In former days the comparative feebleness of the machines in use made it necessary at times to use Leyden jars to secure the strong effects which can now be produced more agreeably by the ordinary spark discharge from a knob electrode. The jars were used by first charging them from a machine, and then bringing them to the patient and discharging them through him by means of conductors. They were also used in connection with an apparatus for regulating the sparking distance, which is known as Lane's unit jar and discharger, and in a book on "Electricity and Medical Electricity," written by Adams in 1791, the frontispiece illustrates a physician of the period electrifying the muscles of a child's forearm in this manner with ordinary conducting-cords and electrodes.

This mode of treatment, however, seems to have been completely forgotten, for it is not mentioned in later writings so far as I am aware. In recent years a much better method of using Leyden jars has been devised and brought to perfection by Dr. W. J. Morton of New York, and, as worked out by him, it has now become a regular and generally accepted method of treatment. In a report presented to the American Electro-Therapeutic Association in 1900, the early methods of using Leyden-jar discharges are fully described, with diagrams; the method of Dr. Morton (see next section) is compared with the ancient methods, and its utility and originality are upheld.

129. **Dr. Morton's Method.**—In the illustration of the Wimshurst machine (Fig. 117) two Leyden jars are shown with their inner coatings connected to the prime conductors, one to each; the outer coatings are also connected by a wire, which can be removed at will. When the outer coatings are disconnected, or the jars are removed entirely, the machine in action produces a stream of thin purplish sparks; and if the finger be placed between the discharging electrodes, the sensations, though unpleasant, are of the nature of a slight pricking rather than of a shock. If the jars are now connected to their respective electrodes, and their outer coatings are joined by the wire, the sparks between the electrodes alter their character, becoming less numerous, brighter, longer, and more noisy. They also produce severe shocks if the fingers are placed in their path. As the distance between the knobs of the discharging electrodes is

increased, the sparks become louder, more vivid, and less frequent, until the air-gap has become too great for the discharge to cross. If the wire joining the outer coatings of the jars be interrupted by a short air-gap, sparks will leap across it simultaneously with those passing between the electrodes.

Many machines are fitted with a pair of binding-screws in the path joining the outer coatings of the Leyden jars. This makes it easy to connect or disconnect this part of the circuit. When a wire is used to bridge over the interval between the binding-screws, the outer coatings are connected, when it is removed they are disconnected. Dr. Morton of New York has advocated the use of this portion of the circuit between the outer coatings for

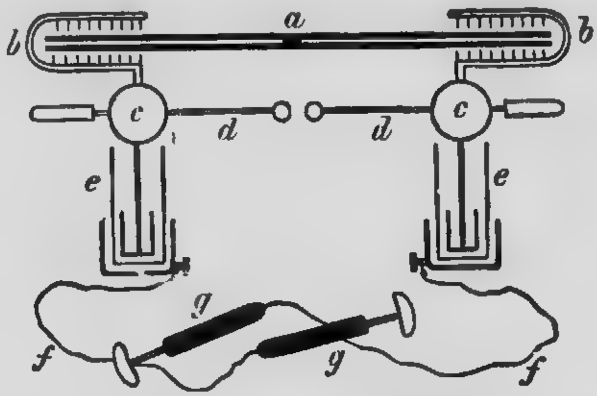


Fig. 123.—Plan of Dr. Morton's Method.

a, Plates of machine; *b*, collecting combs; *c*, prime conductors, with discharging-rods, *d*; *e*, Leyden jars; *f*, *g*, wires and electrodes attached to their outer coatings.

purposes of treatment. With a pair of ordinary conducting-cords and electrodes attached to the binding-screws mentioned above, Leyden-jar shocks can be administered to a patient, and their severity can be controlled by adjusting the distance between the discharging-knobs of the prime conductors *d*, *d* (Fig. 123). When the machine is in action, a shock is felt by the patient every time a spark passes between the discharging-knobs. Dr. Morton has given this method the name of treatment by "static induction," and the utility of the method for purposes of treatment is undoubted. Further, Dr. Morton has claimed that by the use of very small Leyden jars, and with the discharging-knobs very close together, the shocks become almost

painless, while still setting up vigorous contractions in the muscles, and may then be made extremely useful for purposes of testing.

It is of the utmost importance to adjust the sparking distance between the discharging electrodes on the machine before commencing the treatment ; an eighth of an inch is generally sufficient. With quarter-inch sparks the treatment is severe. but the severity of the shock depends also upon the size of the jars, and is more severe with large jars.

Modern statical machines for medical treatment are now generally fitted with pairs of Leyden jars of several sizes for Morton's method, and have a simple switch arrangement for connecting or disconnecting the jars as required. The rate at which the shocks follow each other is determined by the speed of the machine. The effect produced is comparable to that of a slowly-acting induction coil, and moistened electrodes applied to the bare skin are to be used.

If a helix of wire be introduced between the outer coatings of the jars, high-frequency oscillations can be obtained (Fig. 124).

The regulation of the discharges in Morton's method is effected by adjustments of the sparking distance between the knobs of the discharger *d*, *d*. This varies the potential at which the jars can discharge. It has also been proposed to vary the capacity of the condensers, and this has been done by Marie and Cluzet by using Leyden jars of special shape in which the coatings can be brought near together or separated more widely apart.

Truchot* has designed an ingenious contrivance for applying Morton's method when the machines are unprovided with Leyden jars. A tube of glass is taken long enough to reach horizontally across from one prime conductor of the machine to the other, and a little over, and two tinfoil armatures are glued to its outer surface at points where they touch the two prime conductors.

Inside the tube two movable metallic cylinders slide ; they act as the inner coatings, and correspond to the outer armatures of tinfoil. When pushed in a certain distance, their coatings come face to face with those on the outside of the glass tube. A pair of conducting-rods with binding-screws are attached to them, and the cords for the patient are fastened to these. The capacity can be varied by displacing the internal armatures from their position in the neighbourhood of the outer coatings.

* *Archiv. d'Élect. Médicale*, 1889, p. 333.

In France the name *franklinization hertzienne* is often applied to Morton's method, and the opinion has been expressed by some writers that the discharges through the patient in Morton's method are oscillatory discharges of high frequency. Reference to the formula given in § 130 will show that this is not the case, because the resistance of the body is too high and the self-induction is too low to give the conditions necessary for oscillations in the circuit. Taking even the most favourable estimate of the resistance, the other quantities must differ considerably from those of the usual conditions of the experiment.

Mr. Rimington, writing on this subject in the *Electrical Review* some years ago, calculated a case for a Leyden jar of about one pint in size, the capacity of such a jar being taken at 0·0012 of a microfarad. He says: "Suppose we take the resistance of the human body as 300 ohms, then the self-induction in the current must be greater than 27 microhenries to obtain oscillations, while the self-induction of the human body and the spark-gap would be less than this. With a jar of greater capacity the case will be still worse," and we may add that with a higher figure for the resistance of the body, the case will be much more unfavourable to the existence of oscillations.

CHAPTER VII

HIGH POTENTIAL APPARATUS—DISCHARGES OF HIGH FREQUENCY—DIATHERMY

Oscillatory discharges—High-frequency apparatus—Oudin's resonator—Modes of application—Electrodes—Diathermy.

130. **Oscillatory Discharges.**—It has already been stated (§ 13) that, under certain conditions of the discharging circuit, the discharge of a condenser is an oscillatory one. The oscillations die away very quickly, but while present they may have a periodicity of hundreds, of thousands, or of millions, a second.

The conditions which determine whether a condenser discharge shall be oscillatory or not were expressed mathematically by Lord Kelvin (then Professor William Thomson) in 1853.

He showed that the factors concerned were the resistance R of the circuit, its self-induction L, and the capacity C of the condenser. Then, if the resistance of the circuit is greater than the expression $\sqrt{4L/C}$, the discharge is a continuous one; but if the resistance is less than that quantity the discharge is oscillatory.

To illustrate the phenomena by analogy the behaviour of water in a hydraulic apparatus is commonly employed. Imagine two jars of water connected by a pipe in which is a tap. When the tap is open, the jars are placed in communication, so that water can flow from one to the other. With the two jars standing at the same level and the tap closed, one jar is filled with water and the other is left empty. This compares with the charging of the condenser. The tap is then opened suddenly, and the water flows through the pipe, until finally a state of equilibrium is reached, with the water standing at the same level in both jars. This represents the discharge of the condenser. If the pipe of communication is narrow, there is resistance to the free passage of the water, and the flow is a

continuous gradual one. If the pipe is a wide one, the water flows rapidly, and equilibrium in the two vessels is only reached after a series of oscillations in which the height of the water level is alternately greater in the first and in the second of the jars.

So, again, the discharge of a condenser has been compared to the vibration of a spring which has been bent and is let go. If free to move, the spring reaches its position of rest only after a series of oscillations or vibrations. It comes to rest without oscillations if its movement is opposed by sufficient friction. In the case of the electrical oscillation friction is represented by the ohmic resistance of the circuit.

With small capacities and with small self-inductions, the rate of oscillation is more rapid than with large values of either of these components.*

For rapid oscillations circuits should have small capacities, low self-inductions, and very low resistances. Increasing the capacity or the self-induction slows the rate of oscillation, and increasing the resistance damps the tendency to oscillation, so that any increase of resistance above a certain critical value will altogether damp out the tendency to oscillation.

A most lucid exposition of this subject will be found in Lodge's "Modern Views," Lecture 3, on "The Discharge of a Leyden Jar." This should be studied by everyone who intends to use high-frequency apparatus. Sir Oliver Lodge has pointed out that it was Joseph Henry of Washington who first arrived at the conviction that the discharge of a Leyden jar was oscillatory, and he quotes the following remarkable words of Henry: "The phenomenon requires us to admit the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is attained."

Of late years D'Arsonval, Nikola Tesla, and Elihu Thomson have developed the study of these "high-frequency" phenomena, and have obtained some remarkable results. The apparatus required is comparatively simple; the principle is to

* he formula for determining the time T of oscillation is as follows: $T = 2\pi\sqrt{CL}$, when the resistance of the circuit is very low, as is the case in the solenoid of a high-frequency apparatus (Fig. 123). When the resistance is high, the equation becomes the following: $T = \dfrac{2\pi\sqrt{CL}}{\sqrt{1 - \dfrac{CR^2}{4L}}}$

charge Leyden jars whose outer coatings are connected by a helix of wire, or solenoid, as in Fig. 124. The inner coatings of the jars terminate in knobs, whose distance apart can be adjusted to suit the sparking distance of the charging electromotive force. The jars can be charged from a Wimshurst machine or from an induction coil of large size, or, through a high potential transformer, from the alternate-current supply mains. The output is least in the first method.

The jars, when charged to a sufficient potential, discharge in an oscillatory manner across the air-gap and through the solenoid

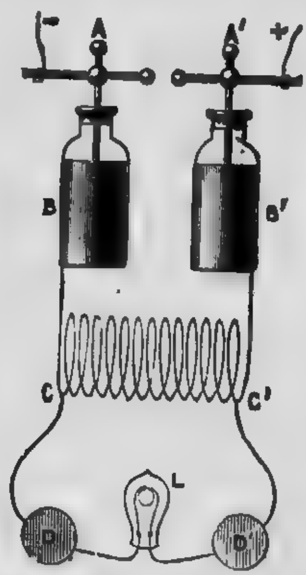


FIG. 124.— ARRANGEMENT OF APPARATUS FOR HIGH-FREQUENCY EXPERIMENTS.

connecting the outer coatings, and the latter becomes the seat of electromagnetic induction effects, comparable to those of an induction coil, so that a derived circuit formed by wires leading from the two ends of the helix yield a current, as do the wires of the "primary current" (§ 48) of a coil. In fact, the apparatus may be regarded as a modified induction coil, the exciting current being supplied from the discharge of the jars instead of from a voltaic cell, while the spark-gap takes the place of the contact-breaker. The suddenness of the discharge causes the changes in the magnetic field of the circuit to be very rapid, and consequently sets up very

powerful induction effects, both in the solenoid itself (self-induction, § 47) and around it (mutual induction), and a secondary coil wound over the solenoid gives very conspicuous effects. Fig. 124 shows an arrangement, due to D'Arsonval, for demonstrating high-frequency effects. D, D′, represents two persons holding between them an incandescent lamp L, and having their other hands connected to the terminal points of the solenoid; under these conditions the current between C and C′ traverses the lamp and the arms of the two experimenters, and the lamp glows brightly, though they feel no shock.

The solenoid is usually made of about twenty turns of thick copper wire. Although the true ohmic resistance of the whole helix is excessively low, only a very small fraction of an ohm, its impedance or virtual resistance to these very rapidly oscillating currents is so high that if two neighbouring turns are approached by a finger there will be strong sparking from one turn to the next through the alternative path offered by the finger-tip, in spite of the relatively enormous ohmic resistance of the latter; and if a straight or slightly bent piece of copper wire be brought near to the two ends of the coil, loud crackling sparks will leap to it. Professor Fleming,* in dealing with this matter, says: "If the difference of potential between the ends of a conductor is established with great suddenness, the resulting electric flow is less and less determined by what may be the true resistance, and more by the inductance of the conductor. We have a mechanical analogy in the case of impulses or sudden blows given to heavy bodies, which well illustrates how strikingly force phenomena may be altered when for steady or slowly varying forces we substitute exceedingly brief impulses or blows."

"If an explosive, such as gun-cotton, is laid on a stone slab in open air and simply ignited, it burns away with comparative slowness, the slab is uninjured, and the evolved gases simply push the air away to make room for themselves. But it is well known that by means of detonators the same explosive can be fired with enormously greater rapidity, and in this case the blow or impulse given to the air is so sudden that it has not time to be pushed away, and its incapability of receiving a finite velocity in an infinitely small time bestows on it an inertia resistance, which causes nearly the whole of the effect of the

* "The Alternate-Current Transformer," vol. i.

explosion to take effect downwards on the slab, and this last is shattered. The inductance of conductors introduces a series of phenomena which are the electrical analogues of the above mechanical experiment. A conductor of sensible inductance can no more have a current of finite magnitude created in it instantaneously than a body of sensible mass can have a finite velocity instantaneously given to it. In both cases there is an immense resistance to very sudden change of condition. Accordingly, the study of the behaviour of conductors under exceedingly sudden electric blows or electromotive impulse leads us to consider some very interesting effects."

131. **The "Skin Effect."**—Another point of importance in the phenomena of high-frequency currents is one which is commonly spoken of as the skin effect. By this is meant that, with rapidly varying currents, the distribution of current in the thickness of a wire conductor is irregular. Silvanus Thompson, in writing on this point, says that with rapid frequencies the currents do not flow equally through the cross-section of the conducting wire, but are confined mainly to its outer surface. He mentions that even at a frequency of 100 per second, the current at a depth of 12 millimetres from the surface is (in copper) only about one-seventh of its value in the surface layers. In iron wires the depth of the skin for one-seventh value is about one millimetre. For such rapid oscillations as the discharge of a Leyden jar through a short, straight copper wire where the frequency is one of several millions, the conducting skin is probably less than one-hundredth of a millimetre thick. Hollow tubes in such cases conduct just as well as solid rods of equal outer diameter. The conductance is proportional to perimeter, not to section.

In some experiments of Sir Oliver Lodge,* two wires of very different thicknesses were taken; each wire was about 100 inches long, and was bent into a single circle. One had an ohmic resistance of 2·6 ohms, and the other of 0·004 ohm; thus, one had a resistance 650 times greater than the other. The virtual resistances of the two wires, for rapidly varying currents, were very different from their true ohmic resistances, and their relative conductivity for these currents was also very different from their relative conductivities with steady currents. The resistances were found to be 4 and 6 ohms with oscillations at the rate of a quarter million per second, 43 and 78 ohms at three million

* "Lightning Conductors and Lightning Guards."

oscillations, and 180 and 300 ohms respectively at twelve million oscillations.

132. **Magnitude of High-Frequency Currents.**—That the currents which flow through the experimenters' bodies and the lamp in D'Arsonval's experiment are really large must be accepted. Their magnitude varies with the apparatus us d, and a good apparatus for medical purposes gives readings up to 500 milliampères or more of steady current when measured with a hot-wire instrument (Fig. 30). The difficulty in understanding why they should produce such slight physiological effects is best explained by reference to the theory of ions. We shall see later on that the effects produced by the passage of currents through the body are chiefly to be explained by that movement of ions which constitutes the current in an electrolytic conductor (§ 16) such as the body. The ions move with comparative slowness, and with the rapid changes of direction of current which take place with the oscillatory currents of high frequency, the time is insufficient for any displacement of ions capable of influencing the tissues in the ordinary way. Consequently the muscular shocks and stinging sensations of ordinary currents are not perceived when the currents change their direction with speeds approaching a million alternations in a second.

133. **High-Frequency Apparatus.**—The development of high-frequency apparatus for medical work has taken place almost entirely in France, and is based upon the physical and physiological researches of D'Arsonval. The current from the primary helix is that most commonly used in medical applications, and the arrangement shown in Fig. 125 represents the apparatus in a simple form. The solenoid connecting the outer coatings of the jar is of bare wire, open to the air, as this affords sufficient insulation for most purposes. The current is led off to the patient from the ends of the solenoid. No iron core is use

The methods of applying high-frequency currents to the human body were devised by D'Arsonval, and three modes of application were originally proposed. In the simplest of these the patient is put in direct connection with the extremities of the helix or solenoid, the electrodes used being the ordinary moistened pads already described (§ 67), or some modification of these. They should be of large surface, and must be kept in good firm contact with the skin to prevent sparking and consequent burning at points of imperfect contact. This method is

commonly spoken of as the direct application of high-frequency currents.

The second method is by "condensation" or the condenser couch. The patient is connected to one end of the solenoid in

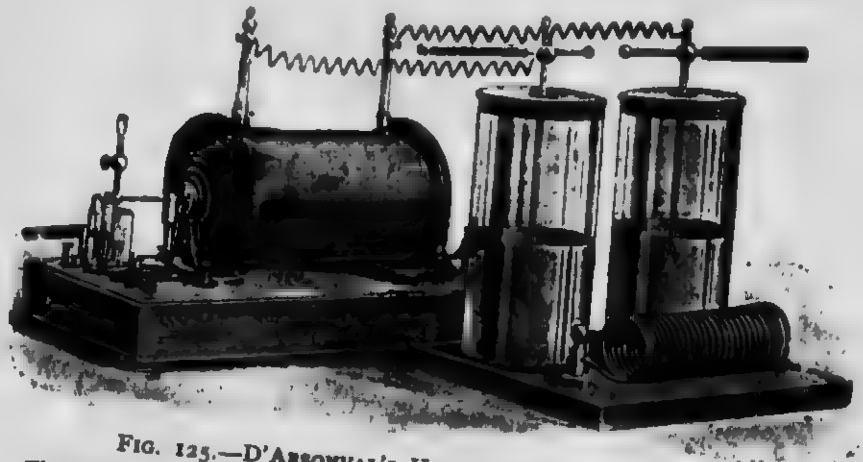


FIG. 125.—D'ARSONVAL'S HIGH-FREQUENCY APPARATUS.
The Leyden jars have the outer coatings joined by a solenoid and the inner coatings fed by an induction coil.

the ordinary way, but the other end is attached to a large plate of metal brought near to the patient, but insulated from contact with him. Thus the metal plate and the body of the patient form

FIG. 126.—COUCH FOR CONDENSATION.

the armatures or coatings of a condenser arrangement having a large electrical capacity, which is alternately charged and discharged as the potentials at the extremities of the solenoid vary. The apparatus is usually arranged in the form of a couch (Fig. 126);

the patient lies upon insulating cushions which separate him from the metal sheet which is fixed beneath. The current passes to the patient either by a handle of bare metal held in the hand, or it may be in the form of an electrode applied upon any desired part of the body.

Another mode of application consists in enlarging the size of the solenoid and enclosing the patient inside it. The patient does not touch any conductor, but is acted upon inductively by the currents in the solenoid which is carrying the Leyden jar

FIG. 127.—WIRE CAGE FOR AUTO-CONDUCTION.

discharges. The "eddy" currents generated in the patient by induction are considerable, so much so that an incandescent lamp held between his two hands is brightly illuminated. This method is called treatment by auto-conduction. Horizontal solenoids enclosing a couch are made, and also vertical solenoids in which a patient can stand or sit (Fig. 127).

In these three methods the applications are general rather than local; the whole body is placed under the influence of the currents, and they may therefore be regarded as methods of general electrification.

134. **Oudin's Resonator.**—High-frequency applications have also been used for local effects, particularly in the form of brush discharges. In order to develop these brush-discharge effects it is an advantage to obtain potentials as high as possible. This may be done by the use of a secondary coil, oil-immersed or air-insulated, and placed inside or outside the solenoid or helix of wire, or by an application of the principle of syntony or "resonance." Oudin, in 1892, designed a "resonator" composed of an

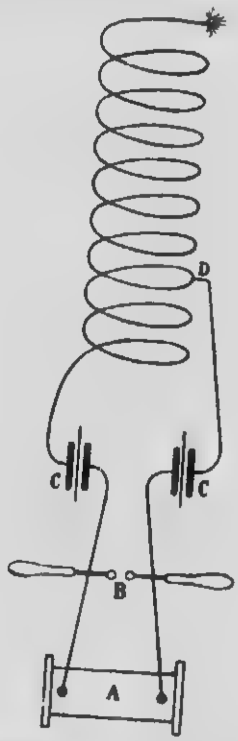


FIG. 128.—PLAN OF OUDIN'S RESONATOR.

open solenoid of wirewhich could be connected up as an extension of one end of the solenoid of a high-frequency apparatus, and served when carefully adjusted or "tuned" to raise the potential to such an extent that a long brush discharge could be obtained from its other or free extremity. These "effleuves" have been shown to have an utility in the treatment of various affections of the skin and superficial mucous membranes. When the effleuve from the resonator is used, the other extremity of the solenoid (proximal extremity) is connected to earth.

It is not necessary to have the solenoid separate from the resonator. One solenoid may be used in both capacities. In this case the lower turns of the wire form the solenoid proper, while the upper turns form the resonator. The outer coatings of the Leyden jars (Fig. 128, C, C) are connected to two points on the solenoid, and the part thus included in the circuit forms the solenoid proper, and is traversed by the discharge current of the jars, while the remaining turns form the resonator. The position of the contact can be adjusted.

135. **Practical Apparatus.**—High-frequency currents can be produced with the static machine, or with high potential transformers connected to the alternating mains; but generally the instruments are worked from Ruhmkorff coils.

In working from the alternating mains precautions are necessary to protect the patient from the currents of the transformer circuit. Several methods have been proposed for this, but the safest is to use two condensers, just as two Leyden jars are used in working from a Ruhmkorff coil.

All manufacturers of electro-medical apparatus now make high-frequency sets in various patterns, and an examination of their catalogues will enable anyone to see how these differ in detail from one another, and to choose the form of instrument which most takes his fancy.

Fig. 129 shows an usual arrangement. On the lower table or platform there are the two Leyden jars. Their inner coatings are connected to the secondary terminals of an induction coil, which should be worked, if possible, with a motor interrupter (§ 103), and also to a spark box, inside which the discharges take place between two metallic knobs, whose distance apart can be adjusted by a handle. Some quick-lime kept in this box is useful to absorb nitrous vapours. The object of the box is to diminish the sound of the sparks, which is loud and disagreeable. The outer coatings of the jars are connected together through the small solenoid fixed on the side of the upper table. The extremities of the solenoid have sockets for the attachment of the conductors which convey the current to the patient. The resonator consists of the large, partly-covered spiral coil of wire wound on a frame, and shown at the top of the figure. It terminates above in a binding-screw for the attachment of a long flexible cord to carry the electrodes.

The upper part of the resonator is covered, while the lower

part is left uncovered, because the point of attachment of the solenoid to the resonator has to be found by experiment, and varies for different applications. The connection is effected by a jointed metallic arm which makes contact with the resonator

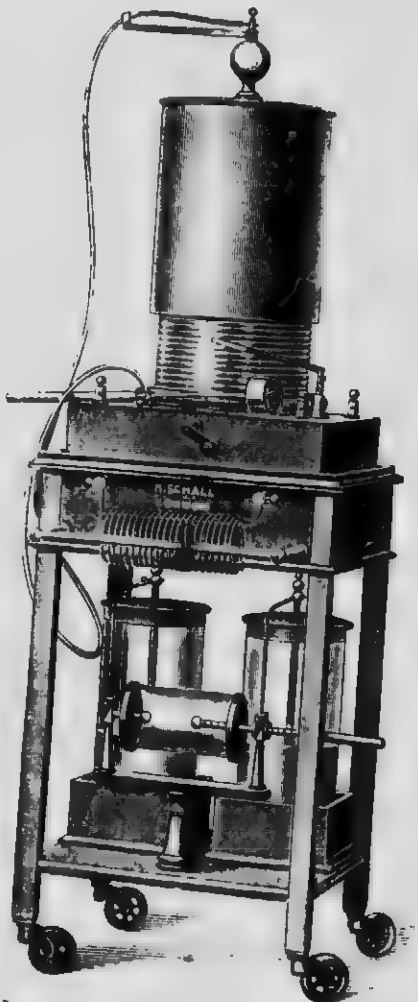


FIG. 129.—HIGH-FREQUENCY APPARATUS, WITH RESONATOR.

wire, as seen in the figure, and it is soon found by experiment that a great effect may be produced upon the discharge coming from the top of the resonator by slight alterations in the point of attachment of the clip. A handle is provided by some makers for slowly revolving the resonator, as this procedure brings the

clip into contact with different parts of the resonator in a slowly progressive manner until the best position is found. The adjustment of the contact to the best position on the resonator wire is the tuning of the resonator, and it is an instructive experience to tune the apparatus under different conditions. For instance, if the position for producing the longest brush discharge be first determined when no patient is connected to the machine, it will be found that the attachment of a patient will throw the apparatus out of tune, and will reduce the length of the brush discharge. If the position of the clip contact be altered, the best position can again be found, and as this point is approached the brush discharge will improve.

FIG. 130.—HIGH-FREQUENCY APPARATUS, WITH OIL-IMMERSED CONDENSERS.

The resonator is not now so much used as it formerly was, because the introduction of glass vacuum electrodes permits of the production of brush discharges in a simpler way.

A compact form of apparatus, with the condensers oil-immersed and enclosed in a box, is shown in Fig. 130. It is not provided with a resonator, but serves for most applications of high frequency. A separate resonator can be adapted to it when required.

136. **Electrodes.**—For general applications of high-frequency currents the metal plate electrodes described in § 67 should be used. They should be well moistened, must be in good contact,

and must not be too small. In high-frequency applications the magnitude of the currents used is large, and if the contacts with the body are small, there is likely to be a local effect on the skin in the form of burns. The same result will follow if the contacts are imperfect, and the current passes to the patient in the form of sparks. Bare metal may be used for the electrodes, provided that its contact with the body is thoroughly good ; thus, a metal cylinder held in the hand is often used for an electrode, as is seen in Fig. 126, where a metal electrode for use in this way is shown affixed to one of the arms of the couch.

In local applications of high frequency the spark or brush effect between the electrode and the skin is made use of for purposes of treatment, and a number of special electrodes have been devised for local use. Of these, the simplest is composed of a number of metallic points very much like the multiple point electrode described in the chapter on Static Electricity (Fig. 122). Other forms of electrode for local effects have the form of closed glass tubes of different shapes and sizes. They are sometimes filled with water or with salt solution, but more usually they are exhausted and sealed to give them a conducting vacuum internally. A wire through the glass forms the connection between the conductor and the interior of these electrodes. Often they are provided with a glass handle, or in place of this they may be fitted with a metal cap at one end for attachment to a socket in an ebonite handle (Fig. 131).

If the finger be approached to one of these glass electrodes when connected to the apparatus, a violet brush discharge and numerous small sparks will be seen to pass between the glass and the finger. This discharge does not come from the inside of the tube, but it is produced at its outer surface by electrostatic induction (§ 5). It corresponds in polarity and in magnitude with the current flowing to the inner surface of the tube from the wire. If the finger be kept in one position for some littl time a sensation of heat will be felt in the skin of the finger, and it can easily be shown that there is an actual production of heat by the discharge. The better the contact between the glass and the skin, the less will be the amount of brush discharge produced, and applications with these electrodes are generally made by rubbing the electrode lightly over the surface of the skin. In applying high-frequency currents locally, these luminous and thermal effects play an important part. Prolonged use of the

electrodes may blister the skin. The vacuum tube electrodes may be connected to the solenoid and give similar effects to those of the effleuve from the resonator, so that the latter may often be dispensed with. In using the multiple point electrode to give a brush discharge with the resonator, care must be taken not to approach the electrode too near the skin, otherwise sharp crackling sparks will pass to the patient, and produce a painful effect, and if repeated several times they may cause small burns, whereas the pure brush discharge is not at all painful. These sparks have been used for their destructive action in a treatment

FIG. 131.—GLASS VACUUM ELECTRODES WITH UNIVERSAL HANDLE.

proposed for cancer under the name of "Fulguration." The glass tube electrodes with partial vacuum present an attractive appearance when in action, as they are luminous from the discharge of the current through the vacuum which acts as a conductor. The luminosity of the gas is due to its incandescence, which tends to heat the glass wall of the tube, and these tubes occasionally crack from this cause. They may also be punctured by a spark, and if this happens the sparks which traverse the crack or puncture produce a disagreeable effect upon the patient, so that the application must be stopped immediately and the tube replaced by another one

For some purposes tubes exhausted to a very high degree are useful. At exhaustions comparable to those of a Crookes tube the phosphorescence of the glass becomes evident, and such a tube is a source, though not a very strong one, of X rays, and can be used on that account for internal applications where an ordinary X-ray tube is inapplicable. Bare metal rods are also used occasionally, as, for instance, in applications to the rectum for the treatment of piles and rectal fissure.

137. **Graduation and Measurement.**—The strength of the applications can be graduated by regulating the current from the induction coil used to supply the Leyden jars, and by alterations in the width of the spark-gap. Further, the number of turns of the solenoid which are in parallel with the circuit of derivation may be varied. Sometimes this is done by a spring

FIG. 132.—HOT-WIRE MILLIAMPÈREMETER FOR HIGH-FREQUENCY CURRENTS.

clip, which may be attached to the solenoid at any desired point, and sometimes by a copper rod, which slides along the inner sides of the turns of the solenoid and short circuits some of them. If the coils of the solenoid and of the resonator form one single spiral, the changing of the point of contact has the effect of varying the number of spires constituting the solenoid proper, and so permits graduation to be effected.

For measurement, hot wire instruments (§ 58) are used. Fig. 132 gives an illustration of one of these instruments. It is desirable to arrange a bye-pass to the milliampèremeter, so that the current only traverses it when a measurement is to be taken. This protects the fine wire from the bad effects of prolonged heating.

The magnitudes of current used in high-frequency applica-

tions range from 100 milliampères up to 800, or even more. It is probable that maximal currents should be used in the general applications of high-frequency currents.

The galvanometer should be placed in series with the patient when direct applications are used, and between the patient and his point of attachment to the solenoid when treatment is given on the condenser couch. It is a common practice to earth one end of the solenoid, and to put the galvanometer upon this earthed side of the circuit. The merits of this procedure are doubtful. Care must always be taken to see that the wires from the apparatus do not come in contact with any part of the patient. If they do they are likely to discharge to the patient, in the form of white noisy sparks, which cause severe burns in an instant. Neck-chains, tinsel wire trimmings of dresses, etc., may divert the current, and lead to painful burns. Hat-pins should be removed. With the method of auto-conduction, measurements of the actual currents circulating in the patient's body cannot be made. Generally it is necessary with this mode of treatment to operate the instrument to its full power. When brush discharges are used, measurement of current is less needed, as the appearance of the effleuve is a guide, but the milliampère-meter may be connected to the top of the resonator.

In all applications of high frequency it is desirable to have a regular action of the interrupter mechanism of the induction coil. Electrolytic interrupters, by reason of the very rapid rate of interruption which they afford, are not very suitable for high-frequency work, especially if currents of large magnitude are required. Professor Fleming* has pointed out that when capacities have to be charged a certain time is necessary, and that the Wehnelt interrupter may have too great a frequency for enabling the charging to take place. This may be observed in high-frequency work by noting that with a very rapid interrupter the length of the spark at the spark-gap of a high-frequency apparatus tends to become less.

138. **Diathermy.**—Of late years much thought has been devoted to the production of sustained high-frequency oscillations, because of their importance for the development of wireless telegraphy. The high-frequency oscillations produced by the apparatus just considered are not sustained. and die out rapidly. With each spark of the coil a short train of oscillations is set up, and then

* Cantor Lectures on Hertzian-Wave Telegraphy, 1903.

there is quiescence until the passage of the next spark. Although the sparks of the discharge appear to the eye to succeed each other very rapidly, the time lost in the intervals between them greatly exceeds the time occupied by their passage (see Fig. 133), so that it has been estimated that during a high-frequency treatment of ten minutes the patient's body is the seat of high-frequency oscillations for a period of only a few seconds. This suggests that if the oscillations could be uninterruptedly sustained, one might expect more striking results from the treatment.

The device which has been most fruitful in results so far for the production of sustained oscillations is that known as Duddell's

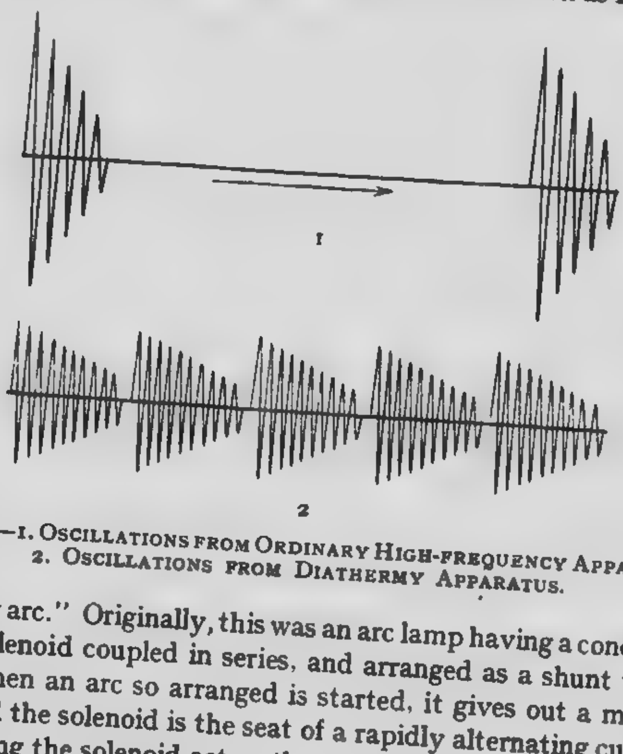


FIG. 133.—1. OSCILLATIONS FROM ORDINARY HIGH-FREQUENCY APPARATUS. 2. OSCILLATIONS FROM DIATHERMY APPARATUS.

"singing arc." Originally, this was an arc lamp having a condenser and a solenoid coupled in series, and arranged as a shunt to the arc. When an arc so arranged is started, it gives out a musical note, and the solenoid is the seat of a rapidly alternating current. By making the solenoid act as the primary of a transformer, this alternating current can be separated and utilized. In its original form the amount of energy which could be obtained in this way was small, but by various modifications in construction the singing arc can now be used as a source of oscillatory currents of considerable energy.

The apparatus which best meets the requirements of medical

practice is one which is made by Messrs. Siemens Brothers, and has been brought to the notice of the medical profession by F. Nagelschmidt. In this apparatus two spark gaps, each of about 1 millimetre, are arranged in series, and in shunt to them is an arrangement of a condenser (capacity) and of a wire spiral (self-induction) in conformity with the requirements of Duddell's singing arc. The current supplied to this circuit requires to be

FIG. 134.—DIATHERMY INSTRUMENT.

an alternating current, because the direct current needs pressures of more than 250 volts to give smooth working. Where pressures of direct current as high as 500 volts can be used, the method is applicable without the intervention of alternating current. The discharges of this apparatus may be roughly represented by Fig. 133, 2.

The diathermy apparatus is shown in Fig. 134, and a diagram of its electrical structure in Fig. 135. With this instrument a

more sustained high-frequency current is obtained, and it is more free from irregularities than that of the D'Arsonval apparatus.

In Fig. 135 the current starting from the plug passes through the primary of a transformer, a switch, *S*, and a resistance, *R*, being interpolated, and also a safety device represented by a horse-shoe loop. This is arranged in the form of a cover to the spark-gap, and unless this cover is in position the current cannot pass.

The secondary of the transformer communicates with a Duddell circuit, in which *F* is a (double) spark-gap, *K* is a condenser, and *W* 1 is the solenoid. One-half of the spark-gap is bridged by a small inductive resistance, *Wd*, which steadies the action. *W* 2 is a secondary coil, in which currents are induced by the oscillations in *W* 1, and these are led off through an ampèremeter, *T*, at 0 and 2. When a less electromotive force is preferred, the terminals 0 and 1 can be used.

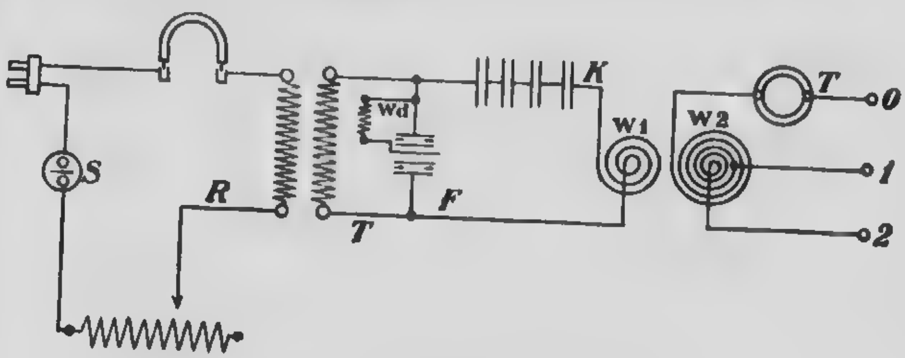


FIG. 135.—PLAN OF DIATHERMY APPARATUS.

If the electrodes attached to 0 and 2 are firmly grasped when the machine is in action, nothing is felt at first, but gradually a sense of warmth begins to be felt in the wrists and forearms, and this heating effect continues to increase with the continuance of the current. If one of the electrodes be small—say, 1 centimetre in diameter—the heat at the point where it touches the body rises very rapidly to a degree sufficient to coagulate the tissues, and this action is used for surgical purposes.

The electromotive force generally developed for the patient is about 800 volts, which is very much lower than that of the D'Arsonval apparatus ; but it has a greater output, and currents ranging up to 2 ampères or more can be applied directly to the patient without any tetanizing effect or shock, and with no

sensation except that of warmth. With currents exceeding an ampère these heating effects are readily perceived.

We saw, in considering the question why high-frequency currents caused no shock (§ 132), that this was due to the very slight amount of ionic displacement; but the production of heat by the currents of the D'Arsonval apparatus was not sufficiently marked to call instant attention to its importance, although the fact that those currents produced thermal effects was noted and recorded at the outset by Professor D'Arsonval. We now recognise that the heating effects of large currents may not only be very appreciable, but may be the chief effect which can be recognised with high-frequency currents, in the absence of the usual ionic effects of direct currents or of currents of low periodicity.

In dealing with the physiological effects of high-frequency currents in a later chapter we shall see that these can be explained satisfactorily as due entirely or almost entirely to their thermal effects.

CHAPTER VIII

THE RÖNTGEN RAYS

Kathode rays—X-ray tubes—Measurement of X rays—The fluorescent screen—Tube-holders and couches—Radioscopy—Radiography—Localization of foreign bodies—Stereoscopic work—Radium.

139. **Kathode Rays and X Rays.**—The discovery of the X rays was made by Röntgen at the end of the year 1895. It followed upon the work of Lenard, who found, when experimenting with the highly exhausted Crookes tubes, that certain effects could be observed outside the tube. Before that time attention had been fixed upon the phenomena within the tube, and outside effects had not been noticed. Lenard, in 1894, following up a hint given to him by Hertz, and working with tubes provided with an aluminium "window," found that such tubes emitted radiations which could be recognised in the open air outside the window, and that these radiations had the power of exciting phosphorescence and fluorescence* in suitable bodies, and of acting upon sensitive photographic plates. He gave the name of "kathode rays" to the radiations which he had thus discovered. In the following year Röntgen showed that a Crookes tube gave out other rays, to which he gave the name of "X rays," and that these were of a different character from Lenard's kathode rays, inasmuch as they easily penetrated considerable thicknesses of bodies opaque to light, and could be made to produce impressions on a photographic plate, whereby any inequalities of density in a given object could be registered in the form of a photograph. Their penetrating power was much greater than that of Lenard's kathode rays.

After this it was a natural step to take a photograph showing

* The word "fluorescence" is used to signify a phosphorescence which does not last for any appreciable time after the withdrawal of the exciting stimulus.

the bones of the hand, and from that moment the modern art of applying X-ray work in surgical and medical practice came into being. Röntgen further showed that by the use of screens painted over with fluorescent materials it was possible for the X rays to produce visible images of bodies without the employment of photographic plates.

A Crookes tube is a vacuum tube in which the exhaustion of the air has been carried to an excessively high degree—viz., about one millionth of the atmospheric pressure. It is so named because Sir William Crookes, in 1891, first interpreted the phenomena to be observed in such an apparatus. It differs from an ordinary vacuum tube or Geissler tube in its appearance when electrically excited. At low degrees of exhaustion a tube of that kind appears filled with glowing gas during the passage through it of an electrical discharge, but the highly exhausted tube shows no such glow. It exhibits instead a peculiar fluorescence of its walls, which is of a pale yellowish-green colour when the tube is made of soda glass, and is blue when lead glass is employed. The fluorescence is caused by a bombardment of the glass by streams of negatively-charged gaseous particles propelled with enormous velocity from the kathode.

These streams of negatively-charged particles constitute the kathode rays, or beta rays, which were shown by Lenard to be able to pass through thin layers of aluminium, and to exist in the air immediately outside the window of his tubes. The effect of the high exhaustion in a Crookes tube is to diminish the quantity of residual gas in the tube to such a degree that the particles set in motion at the kathode are able to move in straight lines for a considerable distance, and to strike the glass wall of the tube without obstruction or retardation through collision with one another. Thus, the higher the vacuum, the more freely can they travel when once set in motion, and the longer is their "mean free path." In tubes of low vacuum their movement is obstructed and arrested before they can travel the required distance, and the luminosity of the gas in such tubes is the result of the energy imparted to it by the collisions and consequent arrest of the negative particles. It was shown by Crookes that when the vacuum in the tube is sufficiently high the particles are propelled in straight lines from the surface or surfaces of the kathode, and continue to travel in straight lines until they strike an obstacle, such as the walls of the tube itself,

or of any body intentionally enclosed in the body of the tube so as to lie in the path of their movements.

Crookes' presidential address to the Institution of Electrical Engineers in 1891 should be read by all who wish to trace the history of the work which led up to the discovery of X rays.*

The particles moving from the kathode or kathode stream are not fragments of the metallic kathode itself, although this view was advanced by certain Continental observers. Before the year 1891, Crookes had shown that this was not the case, and he maintained that they were derived from the residual gas in the vacuum tube, but were in a peculiar "ultra-gaseous" condition, and he described them as representing a "fourth state of matter," or matter in radiation. He uses the following remarkable words: "The molecules . . . at these high exhaustions under electric stress have become exalted into an ultra-gaseous state, in which very decided properties, previously masked, come into play." It has been shown quite recently that the particles concerned in the kathode stream are not atoms or molecules, but are in a much finer state of subdivision, probably having a mass of about one-thousandth part of the mass of an atom, and the word "electron" (§ 3) is used to signify them. The kathode rays are therefore to be regarded as a stream of negatively-charged electrons moving with an enormous velocity, comparable with that of the speed of light. They are therefore not rays in the ordinary sense of the word. In virtue of their nature as electrically-charged and moving particles they are acted upon by a magnetic pole, and can be deflected from their course by its means. It has been proved that X rays are not influenced by a magnet, and this is evidence that X rays differ from kathode rays in not being composed of electrically-charged particles.

When the kathode rays strike any solid object this motion is arrested, and it is their sudden impact and arrest of motion which gives rise to the X rays. The X rays are true rays—that is to say, they are radiations or disturbances in the ether—and they thus differ fundamentally from the stream of negatively-charged electrons which constitutes the kathode rays.

In some of the forms of tube devised by Crookes for showing his effects the kathode rays strike upon the glass wall of the

* See *Journal of the Institution of Electrical Engineers*, 1891, or the *Electrician*, January, 1891.

vacuum tube, or upon bodies enclosed within it, and produce a fluorescence, and at the point where they strike they generate X rays. In the earliest X-ray tubes, also, the kathode stream was caused to fall upon the wall of the bulb, but these tubes were not able to cast sharply-defined shadows, because the rays were emitted from large and irregular surfaces.

X rays differ from the ethereal radiations which constitute light in consisting of irregular solitary impulses, whereas light radiations are even undulations following one another in a regular sequence.

140. **Properties of X Rays.**—X rays have the property of discharging an electrified body by ionizing the air surrounding it. With X rays discharge takes place whether the body be positively or negatively electrified. X rays excite fluorescence in certain substances, especially in the platinocyanides of barium and potassium, in some uranium compounds, as uranium oxyfluoride, in zinc sulphide (Sidot's blende or hexagonal blende), and in calcium tungstate. They act upon sensitive salts of silver, producing the same effect as that of light, and they penetrate opaque bodies, although these are not all equally transparent In a general way it may be said that bodies are opaque to X rays in proportion to the atomic weights of the elements composing them; thus, aluminium with an atomic weight of 27 is more transparent than sulphur, whose atomic weight is 32, and platinum and lead, whose atomic weights are very much greater, are also very much more opaque to X rays than the former elements. X rays have been shown by E. Marx to travel with the velocity of light, and Barkla has proved that X rays can be polarized, and therefore that they resemble ordinary light in consisting of progressive disturbances taking place transversely to the direction of their propagation.

Under different conditions of vacuum rays of different qualities are emitted by an X-ray tube, and this is made use of in practical work to obtain rays of the degree of penetration best suited for different branches of X-ray work.

Any X-ray tube in action emits rays of different degrees of penetrating power, and the output of a tube can be filtered, as it were, by causing it to pass through a layer of some substance which is capable of absorbing the less penetrating rays, while allowing the more penetrating rays to pass. The higher the electromotive force applied to the tube, the greater is the

velocity of the kathode stream, and the more penetrating are the X rays produced by their impact on the anti-kathode.

When X rays impinge upon matter, two kinds of secondary radiation are produced—one a corpuscular radiation of kathode or β rays, and the other an X-ray radiation. The corpuscular radiation is feeble and easily stopped by the thinnest obstacle, but the secondary X-ray radiation may be important. In the case of elements with a lower atomic weight than calcium (atomic weight = 40), the incident beam is merely scattered; and with elements of high atomic weight the secondary radiation is only produced with difficulty, and requires X rays of very great penetration. Within these limits C. G. Barkla has shown that when a piece of metal, or indeed of any substance, is struck by X rays, the secondary X rays produced are of a special quality for each metal or substance, and are of perfectly uniform character, the hardness or penetrating power of the secondary rays increasing with the atomic weight of the element upon which the primary beam of X rays falls. The importance of this lies in the means it gives us of producing X rays of definite quality or penetrating power. Barkla has worked out the details for many substances, taking as a standard the thickness of a layer of water which reduces these secondary radiations to half their value by absorbing them; while Hernaman-Johnson,* utilizing Barkla's investigations, has calculated what he terms the "effective therapeutic range" of the secondary radiations from certain metals, taking the thickness of tissues which reduces the original radiation by one-third as his unit, and gives the following figures: For iron, 0·25 millimetre; for zinc, 0·5 millimetre; strontium, 2·5 millimetre; silver, 1 centimetre. In a later communication† he has expressed the view that some of these figures are too high.

141. **Production of X Rays.**—The essential parts for the production of X rays are two in number—a Crookes tube, suitably modified, which will be spoken of as an X-ray tube, and an electrical apparatus capable of supplying currents at the potential necessary to excite the tube to action.

The instruments in use for obtaining the high electromotive forces needed to excite an X-ray tube are the induction coil, the high potential transformer, and the statical machine. Of these, the induction coil is the most generally used at the present time.

* Proceedings of the Royal Society of Medicine, March, 1912.

† *Archives of the Roentgen Ray*, June, 1912.

The statical machine has too limited an output to rival the results which can be obtained with modern coils or with the Snook transformer (§ 112), although in the hands of experts static machines of very large size have proved capable of giving beautiful results even in rapid radiography of the trunk. The merit of the static machine lies in the fact that it gives a steady and unidirectional current, and, being a self-contained apparatus, it is capable of generating the necessary electromotive force of itself when set in motion.

The Tesla coil, which is a high-frequency apparatus with a secondary winding, is not very suitable for exciting X-ray tubes. Its current is alternating, but a more serious objection is that its discharges, being high-frequency discharges, have a strong tendency to escape into the vacuum tube from the stem or support of the electrodes, in order to pass from the metallic conductor into the gaseous one. If the stems be protected by a glass tube, as is usual, they tend to puncture this, and opposite the point

FIG. 136.—ORIGINAL MODEL OF JACKSON'S FOCUS TUBE.

at which they so puncture the glass stem they quickly heat the wall of the tube and cause it to crack.

142. **X-Ray Tubes.**—The design of the special form of Crookes tube for X-ray work was the work of Professor Jackson, of King's College, London, who contrived a tube with a platinum target fixed in such a position as to receive the concentrated bombardment from the kathode. The X rays in this form of tube are emitted from a small focus on the surface of the platinum target, and the rays therefore cast much sharper shadows than if they come from the general surface of the glass wall of the tube. The platinum target or anti-kathode is placed nearly, though not exactly, at the focus of the kathode in an oblique position (Fig. 136). The anti-kathode acts also as the anode of the system. The kathode is made of aluminium, because this metal does not become disintegrated under the action of the discharges. Most other metals, when they form the kathode in a vacuum tube, are thrown off in minute particles, and are

deposited as a film upon the adjoining parts of the wall of the tube.

The target or anti-kathode is fixed obliquely to the axis of the tube, in order that the beam of Röntgen rays may be directed to one side, and hence may be readily thrown upon the object to be investigated.

Fig. 137 shows a form of the Jackson tube which has been widely used. In it one may see the cup-shaped kathode, the obliquely-placed target or anti-kathode of platinum, and a third terminal which is usually connected to the anti-kathode by a wire outside the tube, and which is thought to act in some way

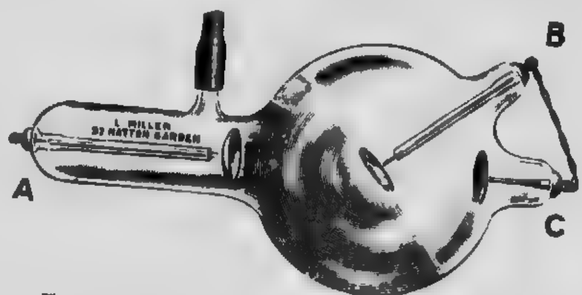


FIG. 137.—COMMON FORM OF X-RAY TUBE.
A, Kathode; B, anti-kathode or target; C, anode or third terminal.

as a regulator. Modern tubes have become more elaborate and much larger.

During use an X-ray tube becomes gradually more and more difficult to excite, and many tubes have been discarded owing to their vacuum having become so high as to resist the full power of the coil used for exciting them. The actual degree of vacuum which is best in a tube will depend upon the electromotive force which is available for exciting it. Thus a tube which is too high for a small coil will serve admirably for another of greater power. There are, therefore, fairly wide limits of vacuum within which X-ray effects can be produced. The higher the vacuum in the tube, the stronger is the electromotive force necessary to work it, and the greater is the power of penetration of the X-ray radiance emitted.

The words "soft" and "hard" are commonly used to designate tubes of lower and of higher resistance respectively. When a tube is "hard" its rays may have too high a penetration, and

will then give a photograph in which the contrasts between the bones and the soft tissues are insufficiently marked.

The increased resistance of an old tube is due to the absorption or "occlusion" of some of its gaseous contents by the wall of the tube or by finely disintegrated particles which are gradually thrown off from the electrodes, and adhere to the glass of the tube. This ageing is especially promoted if the current is allowed to pass through the tube in the wrong direction, because the anti-kathode consists of a metal which is disintegrated by the passage of the current. Care should therefore be taken to avoid this. A tube that has been carefully used gradually acquires a violet tint in the hemisphere corresponding to its effective side, by reason of chemical changes in the thickness of the glass; but a tube allowed to work improperly becomes browned or blackened more or less all over, from the metallic deposit upon its inner surface. This is a strong argument in favour of the use of a rectifier (§ 113).

The appearance of a tube which is working properly is characteristic. It shows a bright green phosphorescence of the glass in the hemisphere which lies in front of the plane of the anti-kathode surface, while the parts which lie behind this plane are almost free from any green colour. This hemisphere of fluorescence is caused by the impact of kathode rays rebounding from the anti-kathode. A faint bluish luminosity in the gas itself within the tube may be seen around the back of the anti-kathode if the vacuum is low, and this appearance of visible gas may be used as an indication of the quality of the tube, for the lower the vacuum, the more evident is the luminosity of the gas. The amount of X rays is often estimated from the brightness of the fluorescent hemisphere if the room is dark. In daylight the fluorescence is easily overpowered. Though fluorescence goes hand in hand with X-ray production, the glass may fluoresce when the vacuum is so low as to be almost useless for X-ray work, but in such cases the true state of affairs is easily recognised by the low resistance of the tube. If the current through the tube is in the wrong direction, no hemisphere of fluorescence is recognisable, and there are green rings and patches of fluorescence of an irregular kind. Tubes have been made with "windows" of special glass, which allow very soft rays to emerge. In the Lindemann tube the window is of lithium borate glass.

As it is practically impossible to find a substance hard enough to stand the full effects of a sustained bombardment by the kathode stream concentrated upon one point on its surface, the platinum anti-kathode is intentionally placed at a little distance beyond the actual focus. Nickel anti-kathodes are now often employed, because they are harder and cheaper.

The size of X-ray tubes has progressively increased since their introduction. It is found that a large tube ages less rapidly than a small one, and also varies less in its condition during the period of an X-ray application.

With modern interrupters the discharges follow each other in such rapid succession that the tubes are soon overheated. Even with moderate work the anti-kathode often becomes heated to redness during an exposure, and its vacuum may be inconveniently changed thereby. To obviate these difficulties,

FIG. 138.—GUNDELACH'S TUBE, WITH HEAVY ANTI-KATHODE.

anti-kathodes backed by an extra mass of metal (Fig. 138), or water-cooled anti-kathodes (Fig. 139), or other heat-radiating devices, are employed.

Tubes with water-cooled anti-kathodes have certain advantages, as they will stand a heavier current than tubes of other types for a short time. They cannot, however, be properly worked in all positions, for one cannot rely on the water being in contact with the target when this is at a higher level than the water. In any case, these tubes require careful handling, but with care they will run for long periods at a time, and with strong currents. If the water boils away, as it may do, it must be replenished in good time, for when there is not any water present, the tube is likely to be ruined in a moment.

For brief periods an X-ray tube will stand a relatively enormous current, because the metal of the target can take up a certain amount of heating before it becomes hot enough to be unfavourably influenced. Consequently, it has been found that many forms of X-ray tube will stand better when used for instantaneous

exposures than for the longer and weaker time exposures, although the currents in these instantaneous exposures may run up to such magnitudes as 100 milliampères.

143. **Regulation of Vacuum.**—The inconveniences arising from the gradual ageing of X-ray tubes when in use have led to the introduction of various contrivances for lowering the vacuum if it becomes too high. Some of these depend upon the inclusion in a side tube of a chemical compound, such as caustic potash, which gives off vapour when warmed. Another method of temporarily lowering a tube is to heat it with a spirit-lamp

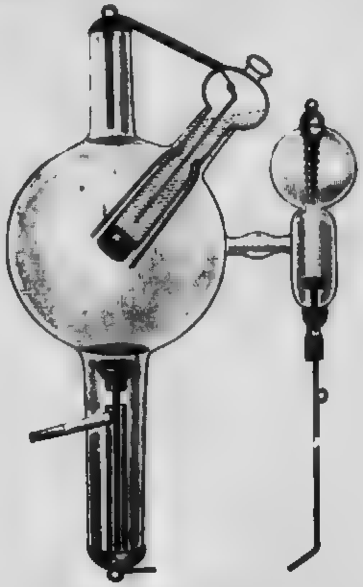


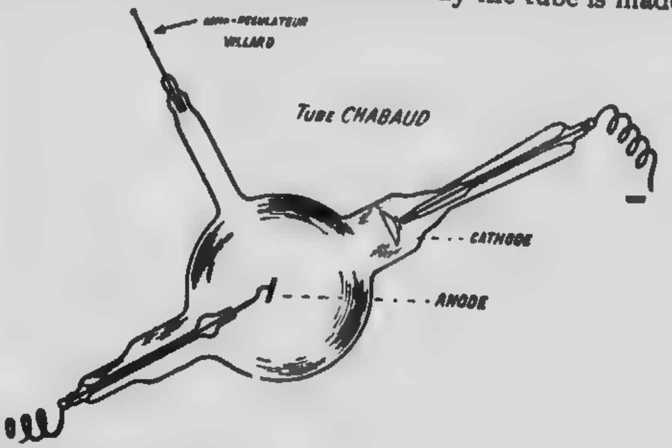
FIG. 139.—TUBE WITH WATER-COOLED ANTI KATHODE AND SIDE TUBE FOR REGULATION.

flame or before a fire. Prolonged baking in an oven at a high temperature will often lower the resistance of a tube more or less permanently.

A simple method which may be used to lower the resistance of a high tube is the following: A sheath of damp lint or cotton-wool is applied to the kathodal end of the tube. It should extend along the glass to a point level with the surface of the kathode. and should also touch the leading-in wire. It gives a negative charge to the outside of the glass, and probably promotes the movement of positive ions to the region round the kathode. The effect of this device upon the apparent resistance

of the tube is very marked, and its use will often permit of the employment of a tube which otherwise would be too hard to work with.

Another tube-regulation method is the use of an accessory side bulb to the tube with terminals between which sparks can be passed at will. These special terminals of the side tube are constructed of mica or of some other material which will emit gas when heated by the passage of sparks, and the gas so disengaged enters the main body of the tube and lowers the vacuum. Fig. 139 shows an arrangement of this sort. The long hinged wire can be so placed that a spark may pass to it whenever the vacuum becomes too high, and in this way the tube is made self-



Medical Supply Association.

FIG. 140.—CHABAUD TUBE WITH OSMO-REGULATOR.

regulating. These tubes need care in management. When they are new, the effect of the passage of a spark through the side tube is apt to be greater than is desired, and the vacuum in the tube may easily be reduced too much ; and with age the side tube fails to emit gas with sufficient readiness.

An excellent method of reducing the vacuum depends upon the power possessed by platinum of becoming permeable to hydrogen gas when heated to a red heat. A thin-walled tubular wire of platinum closed at its outer end is sealed into a side branch of the X-ray tube. It projects outwardly for a distance of about 2 inches. If a spirit-lamp flame is brought into contact with it, hydrogen from the flame is absorbed by the metal, and enters the tube. This is known as the osmo-regulator of Villard. It

is shown in Fig. 140. Palladium may be used instead of platinum, and is more permeable.

The osmo-regulator of Villard is fitted to a French tube known as the tube of Chabaud. In these the anti-kathode is of thick platinum, and the tubes work normally with the anti-kathode at a red heat, and under these conditions their vacuum does not fall, and a source of trouble is thus completely obviated. Unless these tubes are overdriven their vacuum tends to rise slowly when they are running with a red-hot anti-kathode, but the vacuum can be kept constant for very long periods of time by applying a flame to the osmo-regulator at intervals. A spirit lamp or gas-jet on a long insulated handle is provided for this purpose.

Tubes of the Chabaud pattern, when new, should be worked gently, but when in condition, they run best with a current of 1 milliampère. The aim should be to pass as much current as the tube can take without a fall in its resistance. If the pointer of the milliampèremeter shows that the current through the tube is rising, it indicates that the vacuum of the tube is getting lower, and as it is troublesome to readjust a tube when too low, it is better not to let the vacuum become too low.

When the resistance of the tube rises gradually, it is working normally, and as the resistance of the tube increases and the current falls off, a flame can be applied to the osmo-regulator, and the needle of the milliampèremeter watched till it indicates that a proper magnitude of current is again traversing the tube.

Another ingenious method of lowering the vacuum in the tube is due to Bauer. The Bauer valve consists of a U-tube of small diameter, partially filled with mercury. In the wall of the U-tube is an opening closed by a plug of porous earthenware, which is usually beneath the surface of the mercury; but when air is pumped in by a small pump, the surface of the mercury is depressed, and air reaches the porous plug, penetrates it, and finds its way into the cavity of the X-ray tube. When the pressure on the pump (Fig. 141) is removed, the mercury again rises so as to cover the porous plug, and the entry of air ceases. After passing the first porous plug, the air traverses a filtering chamber and a second porous plug, the filtering chamber serves to intercept any dust and some mercury vapour (Fig. 141). Dr. Gustaf Loose,* of Bremen, has recently given a very favourable account of this valve.

* *Archives of the Roentgen Ray*, May, 1912, p. 469.

As the resistance or "hardness" of a tube under working conditions is the factor which determines the quality and penetrative power of the rays which it emits, the estimation or measurement of the hardness becomes important. The resistance of a tube is commonly specified in terms of the length of air-gap which offers an equal resistance, when arranged as an alternative path in parallel to the tube. If the points of the discharger of the coil

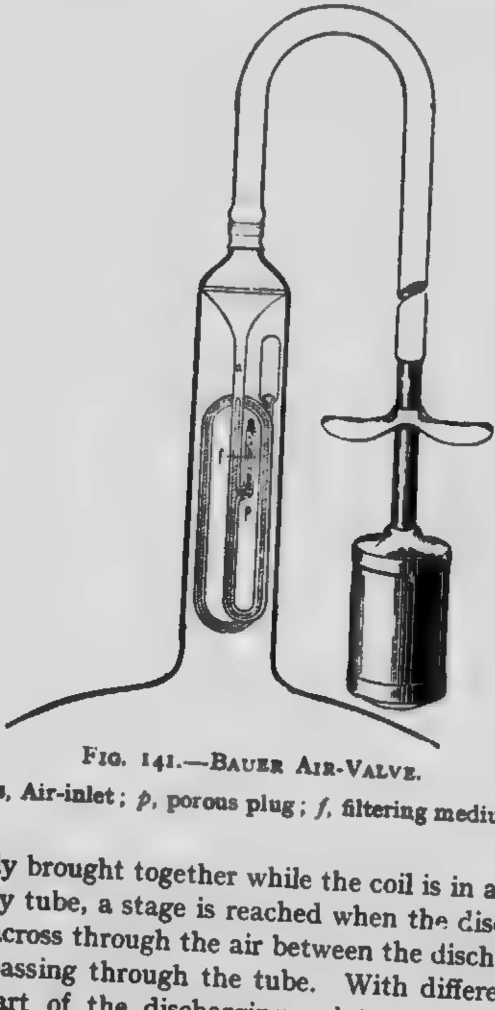


FIG. 141.—BAUER AIR-VALVE.
a, Air-inlet; *p*, porous plug; *f*, filtering medium.

are gradually brought together while the coil is in action supplying an X-ray tube, a stage is reached when the discharge of the coil sparks across through the air between the discharging points instead of passing through the tube. With different tubes the distance apart of the discharging points at which this takes place varies considerably; consequently, this method of measuring the "alternative path" provides a means of estimating the resistance of a tube, or, more correctly, the magnitude of the

electromotive force necessary to excite the tube. The discharger terminals should be points (see § 123) or very small balls.

If the sliding rods of the discharger are suitably graduated in inches or centimetres, the measurement of the alternative path is made easier, and the contrivance has been called a spintermeter or spark-measurer.

144. **Comparison of Tubes.**—The length of the equivalent sparking distance enables one to compare the resistance of X-ray tubes, and so to form an idea as to the electromotive force used and the quality of the radiation emitted, but it is far from being sufficient to act as a guide as to the amount of X rays given out at any particular moment. The two factors, quantity of radiation and quality of radiation, are quite distinct, and must not be confounded together.

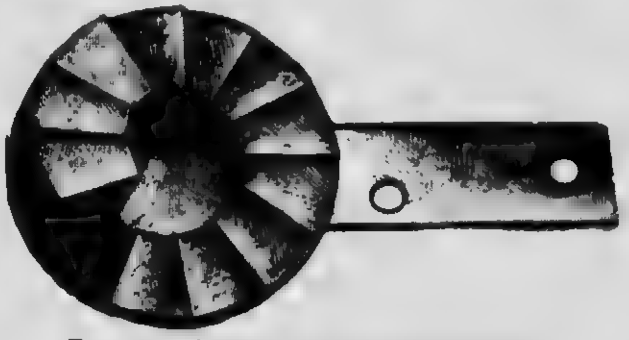


FIG. 142.—BENOIST'S RADIOCHROMOMETER.

Another way of estimating the quality of the X rays, or their penetrating power, consists in a comparison of the relative opacities of two or more bodies of different densities with the rays under examination. This is done in a rough-and-ready way when the image of the hand is viewed on the fluorescent screen, and the blackness of the shadow cast by the bones is compared with that thrown by the soft parts. When the bones appear relatively dark the rays of the tube are said to have a low degree of penetration, and when they appear light, and hardly darker than the soft tissues, the tube is said to be giving rays of high penetration.

L. Benoist has invented a simple instrument, the radiochromometer, for observing the relative opacities of dissimilar bodies, using for comparison silver and aluminium. Professor Röntgen had previously designed a similar apparatus for com-

paring aluminium with platinum. Benoist's instrument consists of a disc of aluminium so cut away as to form a series of twelve sectors arranged in steps of different thickness, from 1 millimetre to 12, around a centre. The aluminium of the centre of the disc is removed and replaced by a circular piece of sheet silver 0·11 of a millimetre in thickness. The image of the whole combination is viewed by a fluorescent screen, and the amount of fluorescent effect transmitted through the silver is compared with that coming through different thicknesses of aluminium. Some of these latter appear brighter and some darker than the silver, and the penetration of the rays is deduced

FIG. 143.—SCREEN IMAGE OF BENOIST'S RADIOCHROMOMETER.

from observing which of the thicknesses of aluminium is most closely comparable to the silver. The more penetrating the rays, the more do they penetrate the aluminium. With a tube of high penetration the ninth or tenth thickness of aluminium throws a shadow comparable with that of the silver. With a low tube the thinner layers numbered two or three do so (Figs. 142, 143).

Wehnelt's and Walter's radiometers are more elaborate instruments for comparing the shadow of a thin silver plate with that of aluminium in graduated thicknesses, and Wertheim Salomonson has also contrived a similar instrument.

Bauer has designed an electrostatic voltmeter for measuring the electromotive force at the kathode of the X-ray tube. It is

a simple apparatus, in which the movement of the pointer is effected by the electrostatic repulsion between two similarly-charged bodies. It only requires to be suspended from the wire leading to the kathode, and is graduated to give direct readings of the penetration quality of the tube, expressed in tenths of a millimetre of lead. As it gives continuous indications on a simple numerical scale, it offers great advantages, and is likely to supersede the older instruments (Fig. 144). Its scale is the same as that of Benoist, and it is called a "qualimeter."

FIG. 144.—BAUER QUALIMETER.

As the different scales indicated on these various instruments are not identical, a scale of comparison is here given.

	Soft.				Medium.					Hard.
Benoist and Bauer	1	2	3	4	5	6	7	8	9	10
Wehnelt	1·5	3	4·5	6	7·5	9	10·5	12	13·5	15
Walter	1	1–2	2–3	3–4	4–5	5–6	6–7	7–8		

These instruments measure the penetrating quality of the rays.

145. **Quantity of X Rays.**—To measure the quantity several procedures have been tried. Holzknecht used a chemical substance, the colour of which grew gradually darker with exposure; a disc of this material was exposed simultaneously with the patient, and the change in colour of the chemical was compared from time to time with a set of standard tints, and the effect

thus estimated. This apparatus has fallen into disuse, but it has given rise to a new unit of quantity of X rays, the Holzknecht unit, expressed by the symbol H. 5 H. is the amount of radiation which the normal skin will stand without developing a dermatitis, though it causes temporary loss of hair.

Sabouraud and Noiré introduced the use of pastilles of platinocyanide of barium for obtaining indications of the quantity of X rays, particularly in connection with the treatment of ringworm. This compound, as is well known to all workers with fluorescent screens, undergoes a change when exposed to X rays. It loses its lemon-yellow colour and becomes brown, and this colour change is regular enough to be used as a means for measurement. If a pastille of the platinocyanide be exposed to X rays at a distance midway between the antikathode of the tube and the surface of the patient, a decided brown colour is produced at about the time when the skin has received the maximum exposure which can be borne without exciting dermatitis (5 H.), and the proper tint is recognized by comparison with a standard supplied for the purpose.

Inasmuch as Sabouraud's pastilles respond to the X rays which actually fall upon them, and may therefore be regarded as measuring the precise effect which it is desired to measure—namely, the quantity of X rays falling upon a given area of the patient—they are superior to any indirect measurement, such as the measurement of the current through the X-ray tube.

The introduction of these pastilles, supplied in a practical form in a book, with a standard tint to show when the pastille had acquired the exact depth of colour corresponding to the maximum dose which the skin would bear, marked a great advance in X-ray therapeutics, and has led to their universal employment. Many attempts have been made to increase their value. As originally used, they presented the drawback that they could not be placed upon the surface irradiated, and besides, all workers have felt the need for the closer measurement of fractions of the unit dose, as the full dose might be more than was required.

Bordier* has suggested certain improvements in the way of using the platinocyanide pastille, and has constructed an amplified scale of tints marked from 0 to 4, which can be used with advantage. He places the pastille upon the surface to be irradi-

* *Archives of the Roentgen Ray*, June, 1911, and June, 1912.

ated, and makes the comparisons in dim daylight. The pastille must be protected from daylight when in use, as daylight tends to restore the original colour of the pastille, and so retards its acquisition of the brown tint when irradiated. He has suggested a unit of measurement which differs from that of Holzknecht, and is based upon a definite chemical reaction—namely, the quantity of X-ray radiation which liberates $\frac{1}{10}$ milligramme of iodine from a 20 per cent. solution of iodoform in chloroform, when the rays fall upon 1 square centimetre of surface of a solution 1 centimetre in thickness. His scale of five tints

FIG. 145.—BORDIER'S CHROMO-RADIOMETER.

allows the estimation of fifteen of these units, which are symbolized by the letter I. The 5 H. dose is equal to 3·8 I. of Bordier's scale, and his five tints are respectively 1·8 I., 3·6 I., 5·8 I., 10 I., and 15 I. Intermediate stages can be recognised.

If the output of rays from the tube is feeble, the indications become unreliable, and he therefore stipulates that the apparatus used shall be capable of producing the change to tint 1 in six or seven minutes, when the antikathode of the tube is 15 centimetres from the pastille.

Hampson* has also constructed a platinocyanide radiometer, consisting of no less than twenty-five graded tints, to represent

* *Archives of the Roentgen Ray*, August, 1911.

the shades of colour progressively assumed by the pastille under X rays. He observes the tints by artificial light, a candle or a carbon filament lamp being chosen as the source of the illumination. The tints of the platinocyanide all look darker by this light than by daylight, and it is easier to recognise small differences of tint under these circumstances. For the epilation dose (5 H.) the pastille, laid on the patient's surface, changes through four tints of the scale, and it is claimed that trustworthy measurements are obtained with a new pastille changing from tint 0 to tint 4, and equally so with a used pastille, changing from 4 to 8, or from 3 to 7, and so on.

Kienboeck measures the quantity of X rays by a photographic process, which estimates the amount of blackening produced on development in a piece of sensitive paper which is exposed to the rays in a black paper wrapper. The development is brief, but this method has the disadvantage of temporarily interrupting the attention of the operator, and does not give the required information until the development of the paper is completed.

Freund* has proposed to measure the quantity of X rays by their effect in precipitating calomel from a solution of mercuric chloride in ammonium oxalate, a reaction first suggested by Von Eder. This has lately been improved by Schwartz, who considers that he can now estimate a dose as small as one-twentieth of the "erythema" dose (5 H.).

The following comparison of the various units proposed may be useful:

Holzknecht	—	3	4	5	6	7–8	10–12	15	20–22
Sabouraud ..	—	—	—	1	—	—	—	—	—
Bordier ..	1	1·8	2·7	3·8	4·7	5·8	8	10	15
Kienboeck ..	3	6	8	10	12	14–16	20–24	28	40–44

146. **The Use of the Milliampèremeter.**—A milliampèremeter can be used to measure the current passing through the X-ray tube, and the production of X rays bears a fairly close relationship to the current so measured; but, in order to measure the effective current through an X-ray tube with accuracy, all current in the wrong direction must be eliminated.

A valve-tube (§ 113) arranged in series with the X-ray tube affords a simple means of ensuring that the current through

* *Wiener Medizinische Presse*, No. 36, 1906.

the tube shall be unidirectional, and experiments with the oscilloscope (§ 111) show that the rectifying action of a good valve-tube is remarkably complete. A spark-gap can also be used.

When a direct current galvanometer is connected up in the circuit of an X-ray tube without any rectification, the deflections obtained represent the difference between the currents which are passing in the two opposing directions. Sometimes, especially with low tubes, the deflection indicates that the inverse current is greater than that producing X rays, while in other tubes the deflection indicates a predominance of current in the right direction. In any case, the insertion of a valve-tube alters the readings from those obtained without it in such a way as to show that its effect in stopping the inverse impulses is all-important for purposes of accurate measurement. In experimenting with three tubes, both with and without a valve-tube in the circuit, the following readings (milliampères) were obtained:

Tube.	Without Valve.	With Valve.
1	0·9	1·0
2	0·25	0·4
3	0·1	0·3

All these were selected tubes which gave fair deflections in the right direction without a valve-tube. Tubes may easily be found in which the wrong direction of current predominates, but with the use of a valve-tube this changes into a flow in the right direction.

An ordinary medical milliampèremeter of the D'Arsonval pattern can be used in the tube circuit. Modifications in the insulation of these instruments are made in order to protect them more fully from the risk of injury by sparks passing between their windings, and small condensers are also fitted to some of them.

We may assume the current going through the X-ray tube, when a valve-tube is used, to be practically or even absolutely unidirectional, and therefore that its mean value admits of measurement by a direct current galvanometer, and we then reach the question whether we are at liberty to assume that the production of X rays is simply and directly proportional to the current, or whether we must admit that the proportion is not a simple but a complex one. Professor Wertheim Salomonson has advanced the view that the production of X rays is proportional to the watts expended in the tube, and not to the current traversing it. This would mean that in order to obtain

a measure of X-ray production we should take into account not only the current, but also the electromotive forces necessary to produce that current, and experience shows that for a given current the output of X rays is greater when the tube is high—that is to say, when the watts expended on the tube are high. More recently the same writer has expressed the view that other factors are also concerned, and that a tube run at high power for a short time gives a larger X-ray output than it would do if the same number of watts were expended on it at a slower rate.

In any case a considerable amount of the energy applied to the tube is wasted in the form of heat, and this alone would prevent a measure of the current or of the watts from being an exact index of the output of X rays, and variations in the thickness of the glass wall of the tube would also influence the calculation.

147. **The Fluorescent Screen.**—This is a contrivance for producing with the X rays an illumination which can be perceived by the eye, and it affords a means of judging of the quality and quantity of the radiations of an X-ray tube, and renders possible the direct inspection of bodies by means of X rays without the intervention of a photographic process.

The principle upon which the fluorescent screen is based is the property possessed by X rays of causing phosphorescence or fluorescence in certain chemical compounds. For the manufacture of screens a fluorescent body—that is to say, one which is luminous only during the continuance of the excitation—is better than a phosphorescent body in which the luminous effect is more or less persistent; and on this account the phosphorescent compounds, calcium tungstate and zinc sulphide, are not now used for screens, as with these bodies there is a persistence of the images or after-effect, which tends to blur the sharpness of what is seen upon the screen. Barium platinocyanide, the compound originally preferred by Professor Röntgen, is still the best compound known for practical use, and commercial fluorescent screens are coated with this material.

Potassium platinocyanide is also used, but does not keep so well, as the salt tends to effloresce, and then is no longer fluorescent. Good screens can also be made with uranium oxyfluoride, but this preparation has not come into general use. Recently screens of a new material have been brought out, but their chemical composition is not stated.

Fluorescent screens are made by spreading an even layer of finely crystalline barium platinocyanide upon cardboard. The crystals must be of uniform size, and should form a layer of uniform thickness. About 4 grains are sufficient to cover a square inch. The barium salt is made into an emulsion with collodion, amyl acetate and acetone, and spread upon the support, which is then left in a horizontal position to dry.

Fluorescent screens are mounted in light wooden frames, and are backed with black paper. A sheet of glass should be used to protect the surface from dust or finger-marks.

The fluorescent light emitted by the screen is of a greenish-yellow hue, and is not of a high degree of brilliancy, and for work with the screen it is necessary to have the room perfectly dark. Some workers enclose the X-ray tube in a covering to exclude the light given out by its walls, and others have recommended the use of tubes coated with a dark-coloured varnish with the same object. As the retina becomes very much more sensitive after a few minutes' rest in darkness (according to Béclère, a period of rest in a dark room of twenty minutes' duration increases the sensibility of the retina 100 times), a short period may be usefully spent in the dark room as a preparation before commencing operations. When difficult cases are to be examined this is a very great help, particularly in the daytime, though after nightfall it is less necessary, as the retina is then already partially prepared. The eyes of the young are much better able to discern faint appearances upon the fluorescent screen than are those of their elders.

The screens should be exposed to light occasionally. The prolonged action of X rays causes a change in colour through which the screens lose the greenish tinge which they have when new, and they acquire an orange-brown tint through loss of water from the crystals of the salt, and in this condition their fluorescent powers are considerably lessened. This change is partly remedied by exposure to diffused daylight, but bright sunshine by heating the screen does harm.

In examining an object with the fluorescent screen, the latter must be kept in close apposition with the object. If this is not attended to the images will be less distinct, and will appear too large, because the pencil of rays emitted by the tube is of a divergent character. The nearer the object is to the tube the greater will be the exaggeration of the size of the image, while

distortions are produced if the object examined be not in a plane parallel to that of the screen. By the use of the screen, much can be learned which will prove of value when the taking of X-ray photographs is being practised. The posing of the limb, so that it is in proper relationship to the tube and to the plate, plays a very important part in successful X-ray photography.

The value of the fluorescent screen in practical work lies in the ease of its application. By its means any region of the body can be examined from all sides, and that in a comparatively short time. Its indications will suffice for a large proportion of medical and surgical cases, particularly for those in which coarse injuries of bones or of joints are being investigated, and for most foreign bodies; also for examinations of the thorax in experienced hands. On the other hand, the screen image is not able to reveal so much of the fine detail as can be seen in a photograph, and for difficult work the latter will consequently be preferred. The action of the X rays upon a photographic plate is cumulative, and thus it can collect during exposure, and can reveal, on development, a number of points which might escape notice in a screen examination. Moreover, the photograph gives a permanent record, and one which can be measured and can be studied by several independent observers.

The cryptoscope or fluoroscope is an arrangement of the fluorescent screen designed to permit of examinations being made in a room which is not darkened. It consists of a camera or dark box, at one end of which is a fluorescent screen, while the opposite end is provided with apertures for the eyes of the observer. The screen is thus viewed in darkness even in a lighted room.

A common size for the fluorescent screen is one of ten inches by eight inches. Larger or smaller ones may also be used. But the small screen is often to be preferred to a larger one, because with a screen much larger than the part under scrutiny the eye may be troubled by the fluorescence of the outlying portions.

The operator must refrain from examining his own hand too frequently, as by doing so he is very likely to prepare the way for chronic dermatitis, a condition which is of extreme gravity. In screen-work there is a tendency to approach the object nearer and nearer to the tube for the sake of the extra illumination which is gained from proximity to the source of X rays, and this is favourable to the production of dermatitis. Moreover, an

interested observer may easily spend many minutes in examining the effects shown by the screen, and may forget that there is a danger of setting up acute dermatitis, if any one part is left close to the tube for a length of time.

148. **Couches and Tube-Holders.** — In modern radiography the tube-holder usually forms part of the couch upon which the patient is placed. Most often the tube is arranged in a box upon a carriage beneath the couch and connected to the coil by long spiral wires, and the beam of rays is directed upwards through the patient to reach the photographic plate or

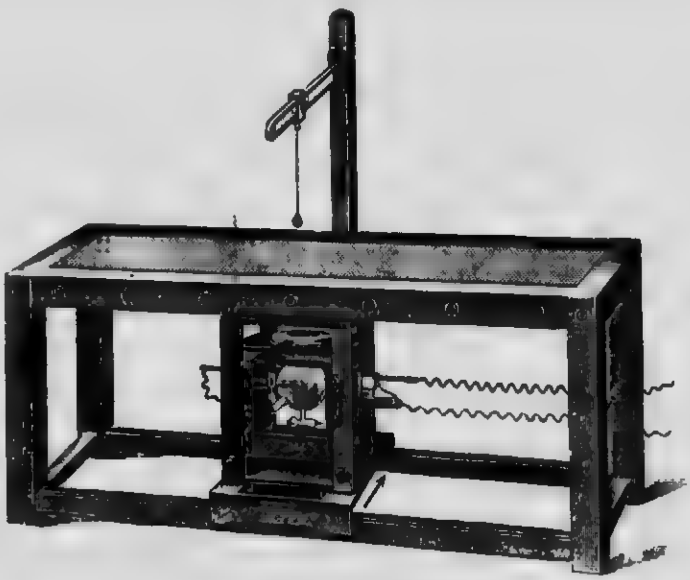


FIG. 146.—X-RAY COUCH, WITH CANVAS TOP.

the fluorescent screen laid above. A diaphragm is fitted to the tube-box, and it runs on rollers, so that it can be brought into position beneath any part of the patient. The appearance of the image can be verified with the screen before the photographic exposure is made. Fig. 146 shows a couch of this kind, of simple construction. The tube-box should either take the tube in a transverse position, with the coil at the end of the couch or in a longitudinal position with the coil at the side, for this makes the disposition of the long wires more easy. An upright post fixed to the tube-box, and carrying a horizontal arm with a plummet over the couch, is useful to indicate the point which is

central in relation to the beam of rays. This is an important point in radiography, in order that the pictures obtained may be taken in a systematic manner, and be comparable with one another, and it is one on which Ironside Bruce* has rightly laid great stress.

The varieties of couches are numerous, and some highly complex forms of instrument have been devised, while new ones continue to be submitted from time to time. These elaborate and expensive outfits appear very cumbrous and

FIG. 147.—SCHMIDT'S APPARATUS.

difficult to manage, but it should be borne in mind that the complication of the apparatus may mean the simplification of the actual work. Rieder's stand is good, and H. Schmidt† has described an apparatus, illustrated by twelve figures of the methods in which it can be used, which fills every requirement of X-ray screen examinations and photography, with patients in the upright and in the horizontal position (Fig. 147).

* "A System of Radiography, with an Atlas of the Normal," London, H. K. Lewis, 1907.

† *Archives of the Roentgen Ray*, September, 1911.

149. **Tube-Stands for Treatment.**—For X-ray treatment a stand to hold the tube and to shield it is required. Here again there is a very great variety of pattern, and the instrument-makers' lists may be consulted with advantage. The requirements of a good therapeutic tube-holder are that it should allow of being placed in any position for the application of the rays to any part of the body, that it should permit the tube to be brought close to the patient, that it should not emit rays in any direction except that wished for, and that it should be fitted

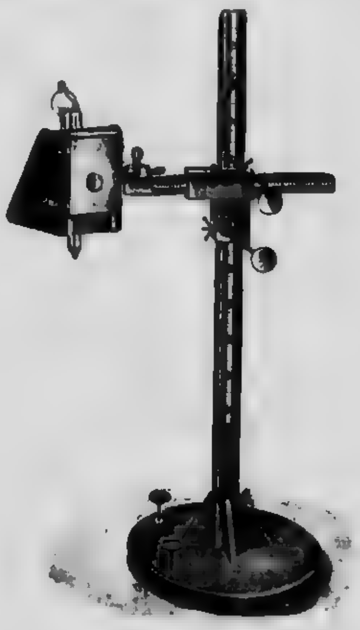


FIG. 148.—TUBE-STAND AND TUBE-HOLDER FOR TREATMENT.

with a pastille-holder for the proper placing of the pastille. The adjustments of the tube to the patient should be made by rack and pinion movements, as without these it is often troublesome to put the tube just where it is wanted.

150. **X-Ray Photographs.**—In medical work X-ray photographs are taken by means of photographic plates enclosed in light-tight envelopes of paper. The plate is usually enclosed in a yellow envelope, which again is enclosed in a black envelope. By this means the action of ordinary light upon the plate is

prevented, but the passage of X rays to the plate is not interfered with.

In putting the plate into the envelopes before exposure a little care is needed, in order that the film or sensitive side may face in the right direction. The plan is to put the plate into the yellow envelope with its film side away from the flap or opening, and then to put this into the black envelope, with the plain sides in apposition. The side with the flap or opening of the envelope is then the side of the glass or non-sensitive side; the other is

FIG. 149.—DETAILS OF TUBE-STAND, SHOWING MILLIAMPÈREMETER AND ENCLOSED SPARK-GAP RECTIFIER ATTACHED TO IT.

the side of the film which must face the X rays. Envelopes of the proper kind can be obtained from the makers of photographic materials.

Plate-holders of polished wood with thin ebonite fronts are also used, particularly when an intensifying screen is made use of. As soon as the exposure is concluded, the plate is removed to a dark room, where its development is carried out in the ordinary way, as in simple photography.

The average exposures with a 12-inch coil with mercury-jet interrupter worked from the mains are as follows (distance, 18 inches):

Hand and wrist	5 to 10	seconds.
Forearm, Elbow, and Arm ..	10 to 20	,,
Shoulder	20 to 30	,,
Thorax	20 to 30	,,
Foot and Ankle	15 to 20	,,
Knee	20 to 25	,,
Leg	20 to 25	,,
Thigh	25 to 30	,,
Hip	30 to 40	,,
Pelvis	40 to 50	,,
Abdomen	50 to 60	,,
Head	50 to 60	,,

With smaller coils longer exposures will be necessary. But it must not be thought that a long exposure with a small coil will give equivalent results to those obtained from a short exposure with a large coil. The larger the coil, the quicker may be the exposure, but in addition the sharper would be the picture.

Various kinds of photographic plates have been specially recommended from time to time, but there does not seem to be any conspicuous difference between one kind and another. It is better to choose one kind of plate and adhere to it, because in this way the peculiarities of the plate during development are the more quickly learned.

As with choice of plate, so with choice of developers; it is best to make use of those with which one is best acquainted. A very simple and convenient developer is rodinal. It has the advantages of easy preparation and of rapid action, and it does not stain the fingers. Hydroquinone with caustic potash is also a good developer, and as with X-ray work the exposures are seldom very far removed from what may be called the minimum normal exposure, a simple developer of maximum strength can usually be employed without the risk of spoiling the plate in the process of developing, and whenever the exposure and the development are both carried out by the same person, it is found that a time is soon reached when one may very closely assimilate time of exposure and strength of developer so as to give the best results. The question of skilful development belongs rather to photography than to medical electricity, and in many cases the plates are sent for development to professional photographers.

An over-exposed plate may be known by a fulness of detail in the whole plate, which is thin if development is cut short, but shows a general blackness of the whole subject if development is

fully carried out, while an under-exposed plate long developed shows very great contrasts, with absence of detail in the parts least blackened. In general, one should give full exposures in order to save time in development

151. **Intensifying Screens.**—In order to reduce the time of a photographic exposure, one may make use of a fluorescent screen placed in contact with the photographic plate. In the early days of X rays these screens were tried, but were open to the objection that they gave a grained or mottled effect to the resulting negative, which rather spoiled its definition. Recently, these screens have been much improved, and are now generally used when instantaneous radiography is to be done, or when it is wished to take an X-ray photograph with the tube at a long distance from the patient.

These screens are similar in nature to fluorescent screens, but are made upon flexible supports, and many chemical substances have been used, such as sulphide of zinc, tungstate of calcium, platinocyanide of potassium, etc. In some instances the nature of the chemical is kept a secret. When used, the screen is put in contact with the film side of the plate, and the glass side of the plate is made to face the patient so that the rays from the tube pass first through the glass, then through the film, and finally reach the intensifying screen, where they excite a luminosity which further influences the sensitive film, and so increases the photographic effect.

152. **Rapid or Instantaneous Radiography.**—By the use of very large currents the duration of the time of an exposure can be much reduced, and it is found that X-ray tubes will often stand enormously strong currents for a short time. Indeed, they stand them better than less currents used for a longer time, because in the case of exposures lasting for only a fraction of a second the discharge is over before it has time to raise very seriously the temperature of the mass of metal forming the anti-kathode of the tube. The heavy discharges are obtained by switching the full pressure of the mains, without resistances, into the primary of the coil. The current may reach a magnitude of 60, 80, or even 100 ampères, which would destroy the coil if it were allowed to continue for any length of time. For interrupters either the electrolytic break or a good form of mercury jet interrupter may be used, and to terminate the exposure an automatic apparatus is employed, which can be set beforehand

to cut off the primary current when the chosen fraction of a second or any other determined period has elapsed from the moment of its closure.

Dessauer dispenses with the interrupter, and closes the circuit through the primary of the coil, placing in the circuit a fuse-wire in an explosive cartridge. This ignites, and blows the fuse to pieces, giving one sudden flash through the tube.

153. **Cabinets and Trollies.**—The apparatus necessary for X-ray work may be assembled together in a cabinet or cupboard with advantage, particularly when the room in which the X-ray work is done is also required for other purposes.

It may also be convenient to have all the apparatus on a movable trolly, like that shown in Fig. 150, and to connect to the mains by means of a cord with counter-weight suspended from the ceiling, just as is done in the case of electric lighting pendants. The cord may then terminate in a lam -socket, which can be slipped on to a plug fixed on the trolly or on the base-board of the coil. The interrupter may be given a place either on the trolly itself or upon a shelf in a convenient corner near the wall-plug from which current is taken.

For military purposes manufacturers have constructed automobile waggons with a complete X-ray outfit, including a dynamo, driven by the engine of the automobile, and a coil or transformer apparatus. The waggon is closed, and its interior can be darkened for radioscopic and photographic purposes by means of shutters.

154. **Protecting Devices.**—The danger of injury from X rays has led to the introduction of protecting devices. Two separate conditions of danger must be guarded against: one is the risk to the patient, and the other is the risk to the operator.

At the present time tubes are generally enclosed either in a box or in a shield made of thick glass, or of some composition which is comparatively opaque to X rays, and many varieties of tube-shield of this type can now be bought. It is almost impossible to find a material which is absolutely opaque to X rays.

As the parts which suffer most from the chronic dermatitis of operators are the backs of the hands, gloves must be used to serve as a protection.

Other protective devices for the operator which may be mentioned consist in the provision of shields or guards at the sides

of fluorescent screens to protect the hands during screen examinations, as this branch of X-ray work has been found to be a fruitful cause of dermatitis. Aprons of heavy rubber should be worn by operators who spend much time near X-ray tubes.

155. **The Orthodiagraph.**—This is an apparatus for making screen examinations of the chest, with a contrivance for mapping

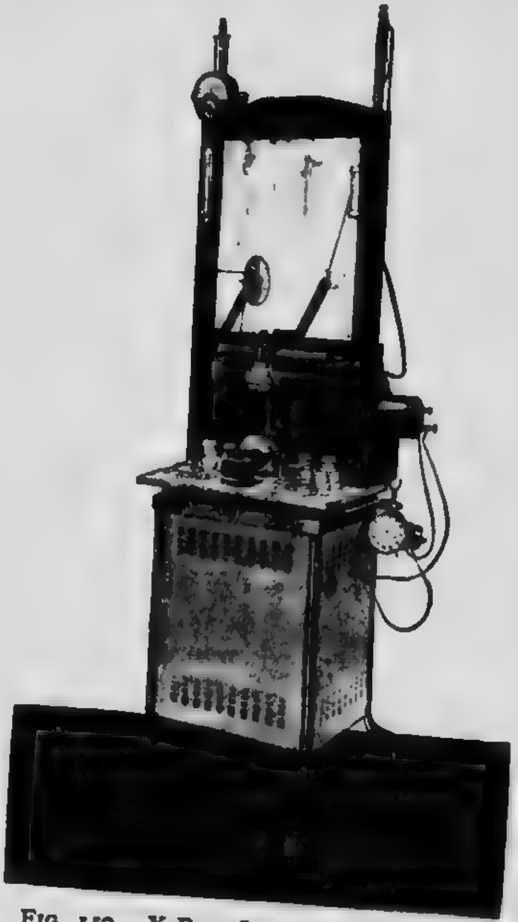


FIG. 150.—X-RAY OUTFIT ON TROLLY.

the outline of the heart in its natural size. This is effected by using a small central beam of the rays emerging from the tube. The tube and the screen move together, being carried on two arms moving on a common hinge. The patient is placed between, and the central beam of rays is brought in succession to a number of points along the outline of the heart's shadow By means of a

pencil moving with the tube and screen and worked by a pneumatic ball a mark can be made upon a large sheet of paper placed at the back of the apparatus, and these marks, when made successively at points on the outline of the heart's shadow, give a record of the shape of the heart in its proper size. With practice, the apparatus can be made very useful, but it has been a good deal superseded by radiograms taken from a distance of 1 or 2 metres—a procedure rendered possible by the use of powerful discharges. With these, and particularly with instantaneous exposures, the contour of the heart in its natural size, or very nearly so, can be obtained in an X-ray photograph, and is to be preferred to the tracing given by the orthodiagraph. For a description of the instrument and the mode of using it, see *Medical Electrology and Radiology*, June, 1906.

156. **The Bismuth Meal.**—The exploration of the alimentary tract with X rays has been rendered possible by the administration of bismuth compounds, as suggested by Rieder in 1904. Bismuth is an element of high atomic weight, and by its opacity to X rays it supplies the necessary contrasts for obtaining details of the alimentary canal in the X-ray pictures.

Half an ounce or more of carbonate of bismuth are given by the mouth, mixed with porridge or with mucilage. The œsophagus, the stomach, and duodenum, and the large intestine may be examined while the bismuth is in them, and valuable indications can thus be obtained. A large number of papers have been published on the subject of the X-ray examination of the alimentary canal by the bismuth method, and these should be consulted.*

It should be borne in mind that the subnitrate of bismuth is not a good compound to use, as cases of poisoning have occurred from its use, the symptoms being attributed to the formation of nitrites by decomposition of the subnitrate of bismuth.

157. **Practical Note.**—The management of Röntgen-ray work demands attention to a number of details, and calls for much careful study and practice. Without experience, the operator may produce nothing but poor results, even with the best and most costly coil.

* "The Roentgen Ray Examination of the Digestive Tract" (F. M. Groedel, *Archives of the Roentgen Ray*, October, 1907); "The Diagnosis of Diseases of the Stomach and Intestines by the X Rays" (C. J. Morton, *Lancet*, July 25, 1908); "The Roentgen Diagnosis of the Stomach" (G. Holzknecht, *Archives of the Roentgen Ray*, November, 1911).

It is in the photography of thick parts of the body that difficulties are met with. The chief of these is due to want of definition, but distortion of the images must also be reckoned with. One often finds, instead of a sharp image on the plate, that there is only a vague blackening, with little or no detail, a result which is due mainly to the phenomenon of diffusion and the action of secondary rays. It was stated in § 142 that the hemisphere of fluorescence seen in an X-ray tube was due to the impact on the glass of kathode rays rebounding from the anti-kathode, and striking the glass wall of the tube. At the points

FIG. 151.—TUBE-HOLDER WITH COMPRESSOR DIAPHRAGM.

where these reflected kathode rays strike the glass they generate X rays which may be called "secondary X rays," and it is these which tend to blur and spoil the definition of the photograph.

Again, if the reverse currents of the coil pass through the X-ray tube they excite an irregular production of X rays, which tend to blur the photographic image.

Various means can be adopted to counteract these bad effects. The valve-tube of Villard can be used to arrest the impulses which tend to traverse the tube in the wrong direction, and by placing a thin layer of aluminium in front of the plate one

may stop the radiations of low penetration while permitting the others to pass through.

The use of diaphragms of lead or of some other opaque body between the tube and the subject has also been recommended, with the object of cutting off as much as possible of the area of glass from which the secondary rays are being given off.

Diaphragms in the form of short cylinders of lead have been recommended, particularly by Dr. Thurstan Holland (Fig. 151) in this country, as being of distinct service in photographing difficult subjects—as, for instance, the hip-joint or the kidney. Their action is probably twofold—partly as a diaphragm and partly as a compressor.

FIG. 152.—LANTERN FOR VIEWING NEGATIVES.

In general, the details of an X-ray photograph can be seen better in the negative than in a print, and the print has the disadvantage of being reversed, whereas the negative is not so.

For the examination or the exhibition of "negatives" a lantern illuminated by artificial light is most generally convenient. The simplest form resembles an ordinary dark-room lamp in which the negative is inserted in the place of the pane of ruby glass (Fig. 152). The effect is improved if a sheet of plain ground glass is placed behind the negative, and if the negatives are very thin a sheet of opal glass is even better. Such a lantern made of japanned tin, with a semi-cylindrical back, and painted white inside, can be made very cheaply by a tinsmith to take the size of negative most commonly made use of. An electric lamp affords the best means of illuminating it.

More elaborate lanterns for the illumination of X-ray negatives are made, both single and in pairs, for stereoscopic work.

158. **The Localization of Foreign Bodies.**—A difficulty which soon shows itself in the localization of foreign bodies by means of X-ray photographs is the difficulty of determining the plane in the limb in which the foreign body is placed. Various plans for localization have been devised. In this country the stand and localizer of Mr. Mackenzie Davidson are in almost universal use.

The principle upon which Mr. Mackenzie Davidson's localizer depends is the measurement of the displacement of the image of the foreign body on the photographic plate which is produced by a measured displacement in the position of the tube. Two exposures are made upon the same plate with the limb perfectly still, a known displacement being given to the tube before the second exposure. This operation is easy with the forms of tube-stand provided for the purpose. Then, as the distance of the tube from the plate and the amount of the lateral displacement of the tube are both known, a diagram can be constructed taking in these two factors and the measured displacement of the image of the body on the photographic plate, and from this, by a calculation, the distance of the foreign body from the surface of the photographic plate can be deduced. In practice the calculations are very much simplified by the use of the localizing apparatus in which two threads represent the axis of the rays from the two positions of the tube. These start from the two points, and are brought down to the two images of the foreign body which are seen upon the photographic negative. The point where the two threads cross in the air above the negative is the point at which the foreign body is situated. That, indeed, is the only point at which it can be, in order to give the two images which it has shown. By means of simple measuring scales supplied with the apparatus, the height or the depth of the body from the surface with which the plate was in contact is readily calculated by measuring the position of the point at which the threads cross in the air. Its distance to right or left from a given point in the photograph can also be measured quite easily.

A fine wire dipped in an aniline dye is tied round the packet containing the sensitive plate; when the limb is placed in posi-

tion and the photographs are taken, the image of the wire is recorded in the radiograph, and the dye leaves an imprint upon the patient's body. After development, the plate is placed beneath the localizer stand, and the two indicators, which are connected with the scale by means of silk threads, are set precisely to the corresponding spot in each of the images—the cord from the right-hand side going to the image on the left, and that from

FIG. 153.—DAVIDSON LOCALIZER.

the left to the image on the right. The point of intersection of the two cords gives the precise depth of the foreign body in the tissue. Fig. 153 shows the arrangement.

Its position laterally will be known by reference to the image of the cross wire, and as an imprint of this will be upon the patient's body, the surgeon can make an incision with absolute certainty of finding the substance sought for. The usual

amount of displacement of the tube for the second plate is 6 centimetres.

In this country the Davidson localizer is used almost exclusively, and it answers its purpose quite satisfactorily. In France a method designed by Marie, of Toulouse, is used and is very clever and simple. It makes use of a stereoscope through which the images (negatives or prints) are viewed. A description of this apparatus and its mode of use will be found in certain French works.*

For the localization of foreign bodies in the eye and orbit Mackenzie Davidson has designed a special form of head rest† which serves to support the patient's head and the plate, and also holds the tube at a fixed distance. The importance of determining the exact position of a foreign body—as, for instance, a pellet of shot—in the orbit may be very great, because the presence of a shot in the globe of the eye might require the removal of the eyeball, whereas a shot in the soft tissues behind the globe might permit the eye to be preserved.

159. **Stereoscopic Radiography.**—In very many cases the position of the foreign body can be estimated with considerable accuracy by the method of taking two photographs and viewing them in a stereoscope. For this the two photographs are taken on separate plates, but the tube is displaced for the second exposure, exactly as in the process just described. The negatives should be viewed direct by transmitted light with a reflecting stereoscope. The binocular image thus obtained has a most remarkable effect in reconstructing to the observer's eye the entire part of the body in which the foreign body lies. It appears to stand out with all its roundness and thickness, and the foreign body can also be seen as it lies in the depth of the tissue in such a way as to give a very real picture of its actual position and depth from the surface.

In order to obtain two photographs which shall be in correct register, some device in the nature of a changing box is used, so that the first plate may be removed after exposure, and a second plate substituted without any movement of the patient. This is secured by using a thin slide or box made with a calf skin or aluminium covering. The photographic plate, enclosed in a

* E. Castex: "Électricité Médicale," Paris, 1903. Bouchard, "Traité de Radiologie Médicale," Paris, 1904.

† Transactions of the Ophthalmological Society, 1894.

black paper cover in the usual way, is supported on a board, which is pushed into place beneath the cover of the box after this has been put in position beneath the patient, and a pair of wedges then raise up the plate and the board into a secure position immediately under the surface of the changing box. A horizontal bar above the couch carries the tube, and allows it to be displaced to either side, for a measured distance, before the second exposure is made (Fig. 154).

A wire may be stretched upon the surface of the calf skin, close over one edge of the plate and parallel to it. This leaves a white line across the end of each negative, and enables the photographs to be brought into correct register.

The Wheatstone form of reflecting stereoscope should be used.

"Two plane mirrors, about 4 inches square, are so fixed on a vertical support that their backs form an angle of 90 degrees with each other. When the observer puts his face close to the

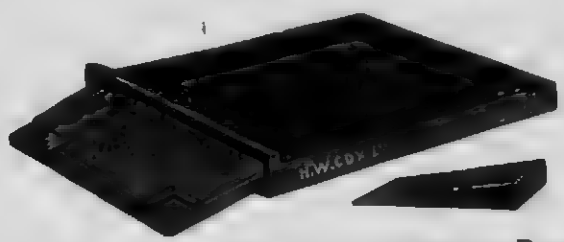


FIG. 154.—SIMPLE CHANGING BOX FOR STEREOSCOPIC PHOTOGRAPHY.

edge where the mirrors meet, so that this edge lies vertically between his eyes, it follows that his right eye can only see what is reflected in the right mirror, while his left eye can only see what is reflected in the left mirror. Now, if the two skiagraphs, taken as already described, are placed so that the right eye image is opposite the right mirror, and the left image opposite the left mirror, each eye will recognize its own picture, and they will combine, as usual, and give rise to a single image in perfect relief (Fig. 155).

"There are several devices for supporting the skiagraphs, and also for simultaneously making them approach or recede from the mirrors. The simplest of all arrangements is to have the mirrors mounted on an upright block of wood, which can be placed upon a table, while the skiagraphs can be supported by any simple means in the proper position. The block supporting the mirrors is attached to a small base with bevelled edges,

which slides in a broad groove, and enables the observer to slide the mirrors towards or away from his eyes. In this way the mirrors can be adjusted to the position which enables the observer to combine the pictures most comfortably. By means of a sliding base the distance of the skiagraphs from the mirrors can be altered at will.

"The Wheatstone stereoscope is peculiarly adapted for X-ray photographs—first because, as everyone knows, a print from an X-ray negative is reversed; for example, if a skiagraph of a right hand be taken, when printed it appears to be a left hand. Now, if such a print be viewed in a Wheatstone stereoscope, it is reflected in one of the mirrors, and is thus reversed to its original position by the reflection. Therefore, if opposite the right

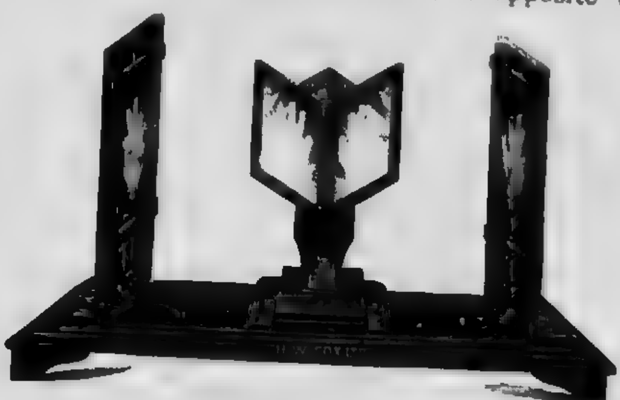


FIG. 155.—WHEATSTONE STEREOSCOPE.

mirror is placed the print from the negative produced when the Crookes tube was displaced to the right side, and opposite the left mirror the print from the negative taken when the tube was displaced to the left, the observer will then see the parts in correct stereoscopic relief, as if he had been looking at them with his eyes placed so that the right eye was at the point occupied by the anode when displaced to the right, and the left eye at the point occupied by the anode when the tube was displaced to the left. If the skiagraphs be viewed under the same angle as they were taken, the stereoscopic picture would show the parts of the true or actual size, and the exaggerated distortion of the single X-ray photograph is overcome. The importance of such a result to a surgeon is great.

"There is no limit to the size of the pictures which can be

viewed in a Wheatstone stereoscope. The largest size the writer has as yet taken stereoscopically is 12 by 15 inches.

"If the right picture be placed opposite to the left mirror, and the left picture opposite the right mirror, a stereoscopic picture will be seen as before, only reversed. For example, in one case a hand will appear as seen from the dorsal aspect; if the prints are transposed, it will appear as a hand seen from the palmar aspect. The same transposition can be effected by turning each print upside down."*

The negatives can be seen in a stereoscope if they are held in proper position, and are illuminated from behind.

The principle of the stereoscope can also be applied to screen work, and Mackenzie Davidson has devised an apparatus for the purpose which will be found described in the *Archives of the Roentgen Ray*, 1901, vol. v., p. 46.

Two similar X-ray tubes are arranged so that the distance between the two antikathodes is equal to the distance between the two eyes. As it is difficult to find a pair of tubes which are of similar quality, a double tube with two antikathodes may be used. By means of a commutator the tubes are illuminated in turn, so that they light up alternately at regular short intervals. The observer examines the screen through two openings which are kept opening and closing synchronously with the alternations of light and darkness of the tubes. Thus the right eye only sees the screen illumination caused by one of the X-ray tubes, and the left eye only sees the illumination caused by the other. These alternations follow one another with sufficient speed for the eyes to receive continuous impressions, and a stereoscopic effect is produced.

160. **Radium.**—This is a metal belonging chemically to the same natural group as calcium, strontium, and barium. Of this series it is the highest member, its atomic weight being 225, which places radium very high among elements of high atomic weight. It is found in minute amount (1 in 3 000,000) in certain ores of uranium, and it is a product of the decay of that element; but it represents only a single stage, for it is itself unstable and in a state of change, passing through several stages, and liberating at almost each step an atom of another element—helium—of very small atomic weight.

* From the paper by J. Mackenzie Davidson in the *British Medical Journal*, January 1, 1898.

The discovery of radium followed the observation of Becquerel that uranium and its compounds had the property of affecting a photographic plate through an opaque layer of black paper, a discovery which was prompted by Röntgen's discovery of the X rays. It was found that pitch-blende, an ore of uranium, had an effect as powerful as that of pure uranium, though containing only 50 or 60 per cent. of that metal. Madame Curie drew the inference that this peculiarity might be due to the presence in pitch-blende of small quantities of some more active body, and after laborious researches in this direction finally discovered and isolated radium in 1898.

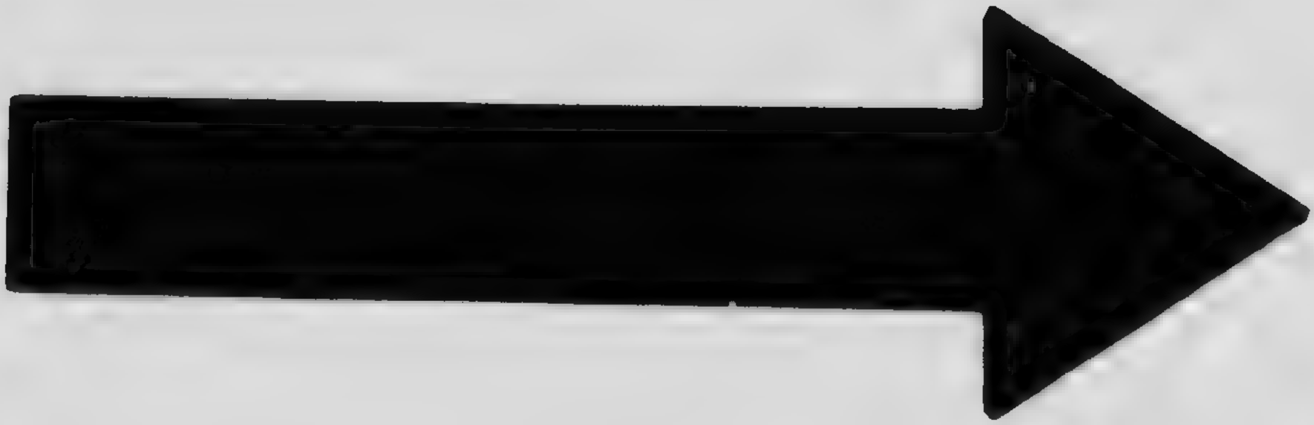
Radium is the most remarkable of a series of "radio-active" bodies, which includes also uranium and thorium. Their existence is determined by the photographic method already referred to, or by the more delicate method of observing the rate of discharge of a charged electroscope when the radio-active body is brought near to it. This effect is due to their power of "ionizing" the air, and of rendering it a conductor of electricity (§ 21).

The element has been prepared in the metallic state, but is readily oxidized, and the preparations of radium which are used are salts of radium, such as the bromide, sulphate, or carbonate.

The best-known compound is radium bromide ($RaBr_2 \cdot 2H_2O$), which exists usually in the form of hard, yellowish, crystalline particles.

Radium compounds undergo atomic changes, and emit three kinds of radiation, known respectively as "alpha," "beta," and "gamma" rays. The "alpha" rays are positively charged material particles, and are now known to be atoms of helium; the "beta" rays are negatively charged, and are electrons in motion, comparable to the kathode rays of an X-ray tube; the "gamma" rays are X rays of highly-penetrating quality. These, although strictly speaking X rays, are so penetrating that, in passing through the hand, for example, there is so little absorption that the bones cast practically no shadow. Rutherford has shown the effect on an electroscope of the γ rays from 30 milligrammes of radium bromide after passing through a foot thickness of iron.

There is a difference between the mode of production of the γ rays and that of the X rays. In the Crookes tube the electrons are gradually started and suddenly stopped, and although theoretically X rays should accompany both start and stop, the latter



only are penetrating enough to get outside the glass tube. In the case of radium the β-ray electron is suddenly started, and gradually stopped, and the acceleration experienced by the β-ray electron expelled in the disruption of the radio-atom is the most sudden known, and it is in consequence of this that the γ rays of radium are the most penetrating type of X ray known. The α ray is scarcely able to penetrate the thinnest sheet of paper, mica, or aluminium, and is completely absorbed in 7 centimetres of air. It is deviated very slightly by the action of a magnetic field, and the deviation is in the opposite sense, and only about one-thousandth as great as that which would be experienced by a β ray under similar circumstances.

The expulsion of the α, β, and γ rays is a sign of the continuous change or decomposition of the element, and the first body produced is a gas or emanation (atomic weight 221), to which the name of "niton" has been given. This again changes to radium A, and so on through radium B, C, etc., until radium F is reached. This body is polonium, discovered by Madame Curie before the discovery of radium. Polonium undergoes a further change, and becomes lead, or, rather, this is thought to be the case. An atom of helium is expelled at most of these steps in the decay of radium.

These different bodies produced by the decay of radium have very different durations of life. Radium itself is thought to have an existence of 2,500 years, radium emanation of only five and a half days, radium F of 202 days.

Radium is not the immediate descendant of uranium, and one, at least, of the intermediates is known as ionium, and is thought to be identical with thorium.

Radium has been applied to the treatment of the conditions for which X rays have been found useful. It has been successful in cases of rodent ulcer and in lupus. It is applied by means of glass or metal tubes containing the radium, which are held or fixed close to the affected part. It is also enclosed in small capsules with a cover of mica, which permits of the escape of beta rays to a small extent, as well as of the gamma rays, and is sometimes used as a layer spread on a flat support.

The activity of a radium preparation is expressed in terms of the radio-activity of metallic uranium, this being taken as unity. Pure radium bromide is considered to be 2,000,000 times as radioactive as uranium, and can be purchased as a marketable com-

modity, the price at the present time being from £15 to £20 a milligramme. Most of the existing specimens of radium are mixtures of radium and barium bromide, and their radium contents vary considerably. A good specimen should produce phosphorescence on a screen of barium platino-cyanide through several copper coins, and should discharge an electroscope with ease at a distance of a yard or more. Radium bromide has the appearance of small crystals or granules of a yellowish-brown colour.

Thorium derivatives have also been prepared for medical use, because the products of the disintegration of the element give, first, mesothorium, and, later, radiothorium. The former emits β and γ rays, and the latter emits α rays, and they can be prepared to give effects as powerful as those of radium. The mesothorium loses half its activity in five years, and the radiothorium in two years.

The activity of a specimen of mesothorium, which is initially equivalent to 1 milligramme of radium, will increase in three years to the equivalent of 1·5 milligrammes, and after ten years will again be equal to 1 milligramme.

A good short account of radium and of thorium will be found in Martindale's "Extra Pharmacopœia" (fifteenth edition); also in a lecture by Professor Rutherford in the *Journal of the Roentgen Society* for April, 1911.

CHAPTER IX

PHYSIOLOGICAL CONSIDERATIONS

Electrolytic conduction—Ionic medication—Cataphoresis—The resistance of the body—Diffusion of current in the body—The capacity of the body—The action of electrical currents on living tissues—Condenser-discharges—The motor nerves and muscles—Unstriped muscle—Electricity as a test of death—Sensory nerves—The brain—Lethal effects.

161. **Conduction of Electricity by the Tissues.**—It has been said that the body is an electrolytic conductor, and the terms used in considering the portion of a circuit in which electrolytic conduction is taking place have been shortly given in § 16. When a battery or other source of direct current is connected to a patient by means of the usual moistened pads, a current flows through the circuit, because the wires, the moist pads, and the body are conductors. The mechanism, however, of the conduction in the non-metallic parts of the circuit is not the same as that which holds good for the wires. Conduction in watery solutions of salts (and the tissues of the body come into this category) takes place only by the conveyance or transport of charged particles or " ions " through the solution, and without this movement of material particles there is no conduction in solutions. The moving particles or ions are the result of the dissociation of the molecules of the salt by the process of solution, so that a solution of sodium chloride in water contains abundance of dissociated ions of chlorine carrying negative charges and of sodium carrying positive (§ 19). When a current is applied, there is a double movement among these ions all along the line joining the metallic electrodes—a procession of the chlorine ions towards the positive pole and of the sodium ions towards the negative, every ion carrying its appropriate positive or negative charge, so that the measurement of the current by a galvanometer in the circuit gives an accurate indication of the

amount of movement of the chlorine ions towards the anode and of sodium ions towards the kathode.

This electrolytic conduction by ionic movement takes place in the body when a current is applied to it, and, indeed, the current is nothing else but a movement of ions taking place in an electrolyte consisting of the fluids of the body which contain an abundance of saline constituents—mainly, chloride of sodium, —but also containing phosphates, sulphates, potassium and calcium, etc.

When the current is applied in the usual manner by means of metallic electrodes covered with layers of moistened material (§ 67), the ionic movements take place both in the saline solutions of the moist pads and in the juices of the body, and consequently there is an interchange of ions at the junction of the pads and the skin, the ions of the pads moving inwards into the skin, and the ions of the body moving outwards into the pads, so that with pads moistened with salt solution (NaCl) there will be an entry of sodium ions into the body from the positive pad, and an entry of chlorine ions from the negative pad, and also an exit of chlorine ions under the positive electrode, and of sodium ions under the negative. It can readily be shown with litmus-paper that the positive pad becomes acid, and the negative pad alkaline.

This movement of ions has been very well illustrated by Leduc, who connected two rabbits in series by means of a pad soaked in saline solution and placed between them. On applying to the skin of the first rabbit an anode moistened with strychnine sulphate, the kathode on the second rabbit being moistened with a similar solution, he found that only the first animal was affected by the alkaloid, which was carried by the current into its body from the anode, while the second animal remained unaffected, the ions migrating into its body from the kathode being harmless SO_4 ions.

He then repeated the experiment with cyanide of potassium. In this case it was the rabbit at the kathode which was poisoned, the toxic constituent of the chemical used being the cyanogen ions which moved inwards from the kathode. The ions moving in from the anode in this case were potassium ions, which are harmless.

At the points in the circuit where the metallic conductors and the electrolyte touch one another the products of the ionic

movement accumulate. At these points the ions, which are electrically charged atoms or groups of atoms (*e.g.*, Na positively charged, SO negatively charged), part with their electric charges and appear in their ordinary chemical form, or else undergo the secondary changes mentioned in § 19. Ordinarily, these final products of the electrolysis, as they may be termed, accumulate in the moist material which is used to cover the metallic surfaces of the electrodes with the object of absorbing these chemical products, and the moist material should be sufficiently thick to hold them, and to keep them from acting injuriously upon the skin during the course of the electrical application.

Thus, if the application of the current is to be a strong one, or is to be given for a long time, the electrode coverings are important, unless it be wished to use the chemical effects of the products of electrolysis for a definite purpose. They are used in this way occasionally in what is known as "surgical electrolysis," when it is desired to destroy tissue, as in the removal of moles, warts, superfluous hair or nævi by electricity.

In surgical electrolysis electrodes in the form of needles are used, and these are inserted into the part to be destroyed. A platinum needle connected to the positive pole will attract chlorine ions, and by secondary action hydrochloric acid and oxygen will be formed, and will exert their chemical action on the tissues in contact with the needle. If the needle be connected to the negative pole, sodium ions will migrate to it, and these will form hydrogen and caustic soda, which, again, act as a caustic, to destroy the portion of tissue in contact with the needle.

If needles of other metals, such as iron, zinc, or copper, be used, their behaviour at the negative pole is the same as that of platinum; but if used at the positive pole, they are acted upon and form ions of the metal which migrate into the tissue. With a zinc or copper needle ions of those metals enter the tissue and exercise a powerful antiseptic effect, which extends beyond the zone of destruction. With iron there is a formation of black oxide of iron, which leaves indelible marks. Iron or steel needles should therefore be avoided in electrolysis, except at the negative pole. Zinc or copper may be used at either pole, but exert their specific ionic action only when used at the anode; and they are used in this way not only as needles, but also as sounds

which are introduced into the urethra, or the uterine canal, or the nasal cavities in order to obtain ionic effects.

162. **Ionic Medication.**—Excepting high-frequency all effects of currents upon the body are effects of ionic movement, but the term "ionic medication" is applied to treatment in which currents are used to produce chemical changes in the region to which the electrode or electrodes are applied. Surgical electrolysis is a form of ionic medication, and the introduction of drugs through the skin from electrodes moistened with them is becoming more and more recognized as a valuable medical procedure. Ionic medication is more complicated than the administration of a drug by hypodermic injection, but it has an advantage which that method does not possess. A hypodermic injection passes into the interstices and lymph spaces, but the ionic movement affects the composition of every cell through which the current penetrates. The principles underlying the electrolytic introduction of drugs are as follows: If the body to be introduced through the skin be a kation or positively charged ion, it will travel from the anode, and the substances which enter from the anode are the ions of the metals, of the alkalies and alkaloids, and of other bases; while from the kathode the various acid radicals are introduced. Thus, in order to introduce ions of zinc into a given area, the proper procedure is to apply a pad of lint or of cotton-wool moistened with a solution of a zinc salt and to bring to the outer surface of the pad a rod or plate of metallic zinc connected to the positive pole of a battery. The current which flows is carried by the zinc ions of the solution which migrate inwards through the skin, and, their number being renewed by fresh zinc ions set free from the electrode, there is no fear of exhaustion of the supply, or of the contamination of the pad by extraneous ions, as would be the case if a different metal were used for the electrode. When the substance to be introduced is one like quinine, or cocaine, or salicylic acid, the supply of its ions must be maintained by the provision of an ample quantity of its solution in the fluid of the moistened pad, and the metal of the anode may be of platinum, in order that extraneous ions may not complicate the process. Carbon discs or gold plates may be used instead of platinum, as carbon liberates no ions under electrolysis, neither do gold and platinum, unless they are made anodes in contact with chlorides. In that case

action takes place and the metal is dissolved. Silver may be used with advantage as the anode for chloride solutions, as an insoluble chloride is formed, and this remains behind.

Leduc (*British Medical Journal*, September 14, 1907) has pointed out that with unattackable electrodes ions are formed at the surfaces of the metal from the electrolyte (namely, hydrogen at the anode, and hydroxyl at the kathode), and that these migrate inwards, and in time reach the skin, where they produce caustic effects.

Edison, in 1890, suggested electrolysis for the introduction of lithium into gouty tissues, and Bordier repeated these experiments, using as electrode a bath containing a solution of lithium, and made a series of applications to a patient with large gouty deposits in the hands. He was not only able to demonstrate the presence of lithium in the patient's urine, as had been done before by others, but—and this is even more striking—he detected the presence of uric acid in the liquid of the arm-baths, thus proving both the introduction of the kation lithium and the extraction of the anion uric acid at one operation. There was also a marked change for the better in the condition of the patient's gouty deposits as a result of the experiments.

163. **Cataphoresis.**—This term is used to signify a movement akin to osmose, which has been observed in liquids submitted to the action of electrical currents. Usually it takes the form of a flow from the anode to the kathode, and flu· can in this way be made to pass through porous diaphragms or membranes against the force of gravity. It has been utilized as a mear of introducing drugs through the skin, and formerly was confounded with ionic medication. It is not impossible that cataphoresis may play a minor part in the conveyance of drugs into the system, when the procedure of ionic medication is being employed. If electrodes be applied to a conducting block of gelatine and a current passed, it is seen after a time that the gelatine under the anode has become drier than before, and the gelatine under the kathode moister. This is partly, if not entirely, an effect of the cataphoric movement of fluid from the anode and to the cathode.

164. **The Resistance of the Body.**—The resistance of a patient's body is mainly a question of the thickness and dryness of the epidermis. It is much higher for the palms of the hands and the soles of the feet than for other parts.

Professor G. Weiss,* measuring the resistances from hand to hand with contacts made through bowls of salt water, found the average resistance in sixteen men to be a little over thirteen hundred ohms, and in seven women fifteen hundred ohms. The reason why the latter showed a higher figure is not very clear, but may have been due to the smaller surface of the hands of the women, or perhaps to a lesser number of sweat glands and hair follicles ; the difference, however, is not great, and would probably be less apparent if a larger number of cases had been measured.

When the electrodes are applied to mucous surfaces, or are in the form of needles thrust through the skin, the resistances are much lower. By a method which eliminated the skin resistance, Weiss found the tissue resistance from shoulder to shoulder to be no more than forty ohms, and from elbow to elbow two hundred and fifty ohms.

Leduc, interpreting the phenomena of skin resistance in the light of the laws of electrolysis, points out that the epidermis behaves as an electrolyte poor in ions. During the passage of a current there is a movement of ions outwards from the tissues of the body towards the electrodes, and inwards from the electrodes to the skin, and the resistance falls, at first rapidly, but afterwards more slowly, until it reaches a steady value, when sufficient ions are present to convey the current without difficulty. The final values differ for different ions ; the simpler ions—as, for example, those of chlorine or of sodium—showing a greater reduction in resistance than the more complex ions of calcium, of cocaine, or of cacodylic acid.

The vascularity of the skin has little or no influence upon the resistance, unless by producing perspiration it causes a filling of the sweat glands with moisture and salts.

The area of the electrodes also has an influence upon the resistance, and this is lower with large electrodes, as might be expected.

Leduc has shown that the conductivity varies in close proportion with the perimeter of the electrode, so that it appears that more current moves from the edges of an electrode than from its centre.

Dubois† has shown that for very brief currents, such as are

* *Archives d'Électricité Médicale*, 1893.
† *Annales d'Électrobiologie*, March, 1899.

used in the testing of nerve and muscle, the resistance of the body is much less than it is for steady currents, and he gives a range of from nine hundred to four hundred ohms as the usual resistance found for such currents. This low resistance is a function of the capacity of the body, and explains certain points observed in electrical testing, which will be referred to later. The higher resistances were those found from hand to foot, or from foot to foot, and the lower were from the trunk to a limb, or with both electrodes on one limb.

The medical practitioner is concerned with the resistance of the body mainly as it affects the question of treatment, and the number of cells required to drive the proper current through the patient. Under conditions of medical practice, and using salt water to moisten the skin and electrodes, the resistance of the body, with electrodes of an area of a few square inches, ranges about one or two thousand ohms—that is to say, an electromotive force of twelve volts (eight Leclanché cells) will pass a current of between six and twelve milliampères. On the palm of the hand or the sole of the foot the resistance will be higher, and may be double these figures. Very high resistances may be observed in hospital patients who have been long confined to bed, as their epidermis is not shed so freely as it is in persons leading an active existence.

Careful measurements of the resistance of patients, and statements as to the degree of resistance in different morbid states, are not of much value or importance. Low resistances have been observed in Graves' disease, in which the skin is usually moist, and high resistances in hysteria, in melancholia, and in paralyzed parts, in which it is dry.

During the progress of treatment the electromotive force in circuit which is employed at the commencement must be reduced gradually to compensate for the fall in resistance which takes place as the skin becomes penetrated by ions; if this is not attended to, the current may become larger than it is intended to be.

During the course of an application the resistance of a patient's body may be calculated by Ohm's law from the galvanometer reading and the electromotive force of the cells, if that be known. For example, with six Leclanché cells in good order the electromotive force will be nine volts, and if the current through the patient be four milliampères, the resistance may be taken as

follows :—$R = \frac{E}{C}$, $E = 9$ volts, $C = {\cdot}004$ ampère, therefore $R = \frac{9}{{\cdot}004}$ or 2,250 ohms. In this way an estimate quite close enough for most cases can readily be formed. When exact measurements are required, the Wheatstone's bridge method (§ 44) should be used. Professor Weiss's paper* indicates a method of overcoming the difficulties of polarization when the battery and galvanometer method is used.

165. **Diffusion of Current in the Body.**—When a current is led into a broad conductor, the lines of flow spread out through the conductor. The current which passes across the unit of sectional area taken at right angles to the lines of flow at that point may be called the density of the current at that point.

In a conductor like the human body it may be necessary to take into consideration the density of current at any particular point, because the physiological effects are partly dependent upon the density—that is, upon the ratio of current to sectional area.

The path of a current between two electrodes placed upon the body surface is not to be marked out simply by drawing a straight line from the one to the other, for the whole of the conducting tissues between the electrodes help to provide a passage for the current, which spreads out from beneath the positive electrode, becoming less and less dense as it occupies a wider and wider sectional area of the conductor, and again grows denser as its lines of passage become once more gathered together to reach the negative electrode.

Fig. 156 shows roughly the divergence of the directions of these lines of current as they pass from a positive electrode placed upon the back of the arm to reach the negative electrode placed somewhere upon the trunk, and it very well illustrates the fact that the current is not confined to the space directly between the electrodes, for some of the lines which indicate its direction actually commence their course by curving downwards through the tissues below the electrode. The minus signs indicate the negative zone or region of virtual kathodes around an anode applied to the body surface.

It also follows that the size of the electrodes is of importance in treatment, for at the surface of contact of a small electrode the density of current per unit of surface, when a definite quan-

* *Vide supra*, p. 271.

tity of current is flowing, will be greater than when large electrodes are used.

166. **The Capacity of the Body.**—The human body regarded as a simple homogeneous conductor should have an average capacity, calculated from its extent of surface, of 0·000044 of a microfarad. Many experimenters who have examined this difficult question have found that the measured capacity is greater than this. It appears almost certain that the increase is to be attributed to polarization effects of an electrolytic character, comparable to those which occur in a secondary cell or storage battery. The existence of this electrochemical

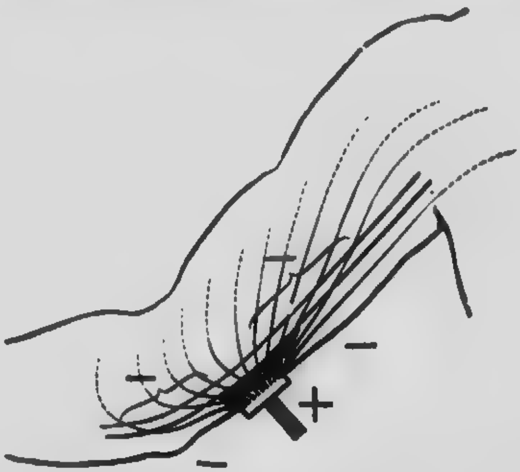


FIG. 156.—LINES OF CURRENT DIFFUSION ROUND POSITIVE ELECTRODE PLACED OVER THE LOWER PART OF THE ARM. (AFTER ERB.)

capacity has been established by Weiss, and measurements of the actual capacity of the body have been made by many Continental experimenters. Thus Dubois estimates the capacity of the body at 0·165 microfarad, Bordier at 0·0025 microfarad, De Metz at 0·0001, Wertheim Salomonson at 0·0002 nearly. There is a considerable discrepancy between these values, and this may be due to the different methods employed, if we suppose that the capacity varies with some other factor, as, for instance, with the electromotive forces applied during the operations for measuring its magnitude.

A very instructive account of the methods of measurement employed by different experimenters will be found in Professor

Castex's book.* In one of the experiments of Wertheim Salomonson, there detailed, the influence of the capacity of the body upon its apparent resistance to high-frequency currents had the effect of reducing the value of the resistance to 373 ohms, although the resistance when measured by a direct battery current had a value of 2,000 ohms. (Compare § 164 for Dubois's results of the low resistance of the body to currents of brief duration.)

The influence of the capacity of the body in high-frequency work is further illustrated by the following experiment: Four persons, hand in hand, were connected to one pole of a high-frequency apparatus, and the current measured between the pole of the apparatus and the first subject gave a current of 151 milliampères; between the first and second the current was 132; and between the second and third 1?8 milliampères.

167. **The Motor Nerves and Muscles.**—The behaviour of nerve and muscle to electrical stimuli under conditions of experiment with dissected tissues is dealt with in works on physiology. The stimulating effect of electrical currents is undoubtedly due to the displacement of ions in the nerve or muscle, and the more sudden the displacement the more stimulating is the effect. In the living subject the phenomena observed under conditions of electrical testing and treatment are as follows: If with the indifferent electrode (§ 67), placed upon any convenient part of the surface of the body, a direct current is applied by means of the testing electrode (Fig. 51) to the surface over a superficial motor nerve, as the ulnar at the elbow, it will be found that a muscular contraction is produced at the instant of closure of the circuit, when the current is about 1 milliampère, and with stronger currents contractions appear both on closing and on opening the circuit. With the active electrode negative the contraction at make or closure is easier to produce than when it is positive. The order in which they appear are:

1. Kathodal closing contraction (KCC).
2. Anodal " " (ACC).
3. Anodal opening contraction (AOC).
4. Kathodal " " (KOC).

The symbols affixed are commonly used for convenience to designate the contractions.

* "Précis d'Électricité Médicale," E. Castex, Paris, 1903.

The contractions are seen only at the make and break—that is to say, only at the moments of sudden alteration of potential.

The smallest current needed to produce a muscular contraction by the stimulation of a motor nerve trunk varies with different nerves. A nerve which is superficially situated responds to a smaller current than a deep-seated one, because it receives a greater fraction of the current. In any case, the current is scattered by diffusion, and only a part of the current indicated by the galvanometer traverses the nerve. For this reason a patient with a thick layer of subcutaneous fat requires a larger current to provoke muscular contractions than is the case with a lean person in whom the electrode can be brought into closer proximity to the nerve to be stimulated. The testing electrode should be of small surface, as this allows us to concentrate the current more effectively.

It has been shown by Dr. Ludwig Mann of Breslau that the nerves of infants and young children require currents of considerably greater magnitude to provoke contraction in their muscles.

Both nerve and muscle react to electric stimulation, but in a normal muscle the direct effect of the stimulation of its fibres is overshadowed by the effect produced upon it through the nerve, for the intramuscular branches of its nerves both receive the impression better, and transmit it to all parts of the muscle more rapidly than the muscular fibres themselves could do if no nerves were present. Still muscle *per se* is irritable and capable of responding to stimuli by a contraction, and a muscle whose nerves have undergone injury may still respond to currents directly applied, although stimuli applied to its motor nerve are ineffective.

The effect of curare in rendering the muscles inexcitable through the motor nerves has long been known. It was discovered by Claude Bernard. In a curarized animal stimuli applied directly to the muscles are able to produce contractions, though stimuli applied through the motor nerves are not. A curarized muscle will react to interrupted currents as well as to battery currents, and the contractions produced only differ from those of a normal muscle in being a little less brisk.

Strophanthine also modifies the muscular contractions. When injected into a frog, it predisposes to the production of a state of tetanus, so that a steady current easily provokes a tetanic

contraction, which may persist after the current has ceased to flow.

Mlle. J. Ioteyko,* in her researches into the behaviour of muscle under electrical stimulation, has shown that the phenomena could be well explained by assuming that all muscle contains two kinds of material—the striated portion and the sarcoplasm ; that both of these elements are contractile, but in different degrees, the former being capable of responding to brief stimuli and contracting rapidly, the latter requiring stimuli of longer duration and contracting slowly. In different types of muscle the relative amounts of each component are different, and different muscles therefore contract at different rates.

The tonicity of a muscle is the expression of the action of its sarcoplasmic element. The contractile power of the sarcoplasm reinforces the effect in all continued muscular efforts. The effect of certain drugs, such as veratrine, in altering the shapes of the muscle curve, is due to an action in heightening the excitability of its sarcoplasmic elements, and the somewhat similar influence of fatigue upon the muscle curve is due to the more rapid rate at which the striated portion becomes fatigued, this permitting of the observation of a preponderating action of the sarcoplasm. Finally, the " sluggish contraction " of muscles observed in certain morbid conditions is a contraction of the sarcoplasmic elements, which persists when the striated portion is thrown out of action by disease.

The contractions produced in muscle by the stimulus of the make and break of a direct current are momentary single contractions, and between the contraction at make and the contraction at break the muscle appears quiescent and relaxed, although the current is traversing it. As a matter of fact, it is not completely relaxed, and a small " contraction remainder," perhaps due to the sarcoplasm, can be observed by appropriate methods of investigation, and the larger the currents the greater will this degree of contraction be. With strong currents a condition of imperfect tetanus is produced, which has been named " duration tetanus." Duration tetanus is not usually seen in healthy muscles with the currents used in electrical testing, but in certain altered conditions it is more readily elicited than in health, and has some diagnostic importance.

168. **Interrupted Currents.**—If the makes and breaks of a

* " Études sur la Contraction Tonique du Muscle Strié," Brussels, 1903.

battery current follow one another in rapid succession, the rapidly succeeding changes of potential cause the muscle to pass into a state of tetanus or permanent contraction. To produce this effect the individual shocks must succeed one another at the rate of twenty per second or upwards.

As the discharge from an induction coil consists of a series of impulses or waves of current (§ 61) occurring about fifty times a second, it is reasonable to expect that their effect upon a motor nerve would be to throw the muscles into a tetanic contraction, and that is what is observed. If the induction coil be arranged to give single shocks, single contractions follow, exactly like those produced at the closure of a battery current, each wave of current from a coil acting as a separate stimulus; but ordinarily the effects are fused by the comparative slowness of the muscular contraction, which requires one-tenth of a second for its completion.

In practical electrical testing it is usual to apply the electrodes to the muscles directly at their motor points, whose position will be indicated later. The individual behaviour of the muscles is more clearly seen by this method than if they be thrown into contraction in groups, as generally happens with stimuli applied to a nerve trunk which supplies a number of separate muscles.

The study of the effect of electrical stimuli upon nerve and muscle has been complicated by the adoption of the induction coil as the usual source of interrupted currents. Induction coil discharges are impulses of irregular form and variable duration, and are by no means the instantaneous discharges which they have been too commonly assumed to be. In recent years the exact character of the electrical stimuli used in electrical testing and treatment has attracted much attention. Hoorweg, Dubois, Huet, Mendelssohn, and others, have attacked the problem in various ways, but there is still much work waiting to be done. D'Arsonval throughout all his researches has insisted on the importance of the wave form of an electric impulse in any study of its physiological effect. Dubois has shown that comparatively slight alterations in the self-induction of a circuit exercise a marked effect upon the current required to provcke the minimal contraction in a muscle, simply through altering the wave form of the current by retarding its rate of rise. Leduc*

* S. Leduc, "Étude sur les Courants Intermittents de Basse Tension," *Archives d'Électricité Médicale*, September 15, 1903.

has shown us that currents interrupted mechanically are superior to those of an induction coil for purposes of diagnosis and treatment, because the impulses can be regulated as to both frequency and duration, and can be exactly measured, while the shapes of the individual impulses can also be exactly determined (Fig. 40). Leduc's apparatus (§ 63) is beginning to come into practical use. In writing of it, Leduc states that the effect upon nerve and muscle is most easily obtained when the impulses occur one hundred times a second and consist of waves each having a duration of one thousandth of a second, followed by a period of no current lasting for the remainder of the period (nine thousandths of a second). If the durations of the individual waves are either reduced or increased the electromotive forces necessary to set up a minimal contraction become larger, although there is no very great difference until the change in the duration is considerably altered, as may be seen from the annexed table taken from Leduc's paper :

Duration of Impulse. Seconds.	E.M.F. necessary for Minimal Contraction. Volts.	Duration of Impulse. Seconds.	E.M.F. necessary for Minimal Contraction. Volts.
0·00001	22·0	0·00100	7·0
0·00010	15·0	0·00200	7·5
0·00020	13·5	0·00300	8·0
0·00030	12·0	0·00400	8·5
0·00040	11·5	0·00500	9·0
0·00050	10·5	0·00600	9·5
0·00060	9·5	0·00700	10·0
0·00070	9·0	0·00800	11·0
0·00090	8·5	0·00900	12·0

Number of impulses per second = 100

In general with interrupted currents it may be said that in proportion as their duration decreases, so the magnitude of current necessary to set up a contraction becomes greater, and currents of very short duration (0·00004 seconds) are unable to cause any excitation of muscles or of nerves.

With rapid interrupted currents, and especially if the intervals of no current are very brief, the effect ceases to be that of a tetanizing current, and the contractions set up are like those produced by a continuous current.

From what is known of muscular contractions in morbid states, we may expect that measurements of the duration of the periods of flow of an intermittent current might be used as a means of estimating the extent of disease in the nerve or

the muscle, for in proportion as degeneration progresses in a muscle, so does it require longer and longer periods of flow before responding with a contraction. Leduc's apparatus permits this to be done, and the same results can be obtained by the use of condenser discharges. In the Leduc apparatus there are so many variable factors, such as speed of motor, duration of time of flow, applied electromotive force, magnitude of current, that the practical use of the apparatus is apt to be rather bewildering to a beginner. The condenser discharge can be used as a simpler contrivance.

169. **Condenser Discharges.**—Condenser discharges provide excellent stimuli for nerve and muscle. Boudet de Pâris, in 1888, advocated their employment, and in his book points out that condenser discharges cause little or no fatigue in muscle, and very little pain, and he also gives plans of the arrangement of a condenser apparatus for muscle testing. Hoorweg* also gives an account of the mode of employment of condensers and advocates their use. Dubois,† in considering the behaviour of muscle and nerve to condenser discharges, showed that, as the charging potential is increased, the required capacity of the condenser decreases rapidly. For example, the minimal contraction in the muscles of man was obtained with a capacity of 0·48 microfarad charged at 12·6 volts, with 0·017 at 35 volts, and with 0·007 at 70 volts, the capacity in the last example being seventy times less than in the first, while the potential is only six times greater. In man a minimum potential of about 12 volts is necessary, because discharges at lower potentials are ineffective, whatever the capacity of the condenser. If the energy of the condenser discharges be calculated, it appears that at low potentials it is relatively large; at high potentials the capacity can be diminished, and the energy required also become less, until a point is reached, after which it again increases, so that there is a relation between potential and capacity, such that a point can be found at which the minimal contraction is produced with a minimum expenditure of energy. The large condenser at low potential wastes energy, because much of the discharge is below the effective minimum; while in the case of a very small condenser and a high potential there may be waste, through the duration of the discharge being too short. The

* "Recherches sur l'Excitation Électrique des Nerfs," Haarlem, 1899.

† *Rev. Internat. d'Électrothérapie*, August, 1900.

discharge of a Tesla coil or high-frequency apparatus fails because the individual impulses, of which it is made up, have too short a duration.

Dubois's experiments emphasize the relationship between the wave form of the stimulus and the physiological effect. The discharge of a small condenser at a high potential is a peaked sudden wave of short duration ; that of a large condenser at low potential is a wave of lower peak and long duration. The former is the more effective stimulus, unless, as in the case of the high-frequency apparatus, its duration is so short as to leave the nerve or the muscle uninfluenced.

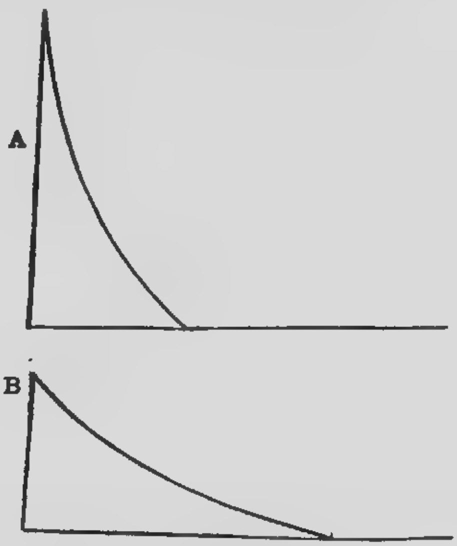


FIG. 157.—CURVES OF DISCHARGE OF A CHARGED CONDENSER.
A, Through a resistance of 1,000 ohms ; B, through a resistance of 2,000 ohms.

Condenser discharges have the advantage that a known capacity, when charged to a known voltage, contains a known quantity of electricity, and discharges this in a regular manner. With condenser discharges the resistance of the circuit is of importance, for it is the factor which determines both the initial magnitude of the discharge and its duration.

To illustrate this point, we may compare two diagrams which represent the discharge of a condenser through two resistances, one twice as great as the other (Fig. 157). The differences between the curves show how important the question of resistance

may be with condenser discharges. In the use of condenser discharges for the testing of nerve and muscle, the resistance of the body presents much less difficulty than one might have expected. Dubois has shown conclusively that for currents of very short duration the resistance of the body is lower than it is for steady currents, and that this momentary resistance changes very little for changes in the resistance to steady currents. He mentions an instance in which the initial resistance of a patient was 51,500 ohms, and that this was gradually reduced to 3,029 ohms by the passage of a constant current with well moistened pads, but examination of this case with very brief currents, while the resistance was decreasing between these figures, showed an almost uniform resistance of 400 ohms all the time.

We may therefore conclude that the use of condenser discharges for the testing of nerve and muscle is not seriously affected by great variations in the resistance of the patient, and that the good points of condenser discharges deserve close consideration in the process of testing nerve and muscle reactions.

Condenser discharges have received a great amount of study on the Continent, and have now attained practical shape for diagnostic purposes. Zanietowski, Cluzet, Doumer, and many others, have studied them very largely from the physiological point of view, and more recently from the point of view of practical electrical testing.

Cluzet* has described a testing set in which condensers are used to take the place of the usual induction coil and battery of cells, and he states that in the vast majority of cases condensers can be very advantageously used to replace the older methods of testing. They cause less pain, they give uniform results, and are simpler to work with.

The principle of the employment of condenser discharges is as follows: Condensers of different capacities—say from 0·01 of a microfarad up to 1 or 2 microfarads, are arranged so that any of them can easily be charged from a battery or from a direct current main, and then discharged through the patient. The condensers are charged to a constant voltage, which may very conveniently be that of the available charging source. Their discharge through the patient gives current waves which are always the same for the same capacity. As the capacity is

* *Paris Médical*, April 13, 1912.

increased, the duration of the discharge wave increases in proportion, so that with a set of, say, ten capacities, ten different wave lengths of discharge would be available, and the response of the nerve and muscle to each could be observed and noted. The different discharges would differ in their duration, and in nothing else (Fig. 158). The short discharges of the small capacities take the place of the test with interrupted currents, and the long discharges of the larger capacities take the place of the continuous current. The condition of the muscle is determined by the wave length of discharge needed to excite contraction (see Chapter XII. for particulars of nerve and muscle testing).

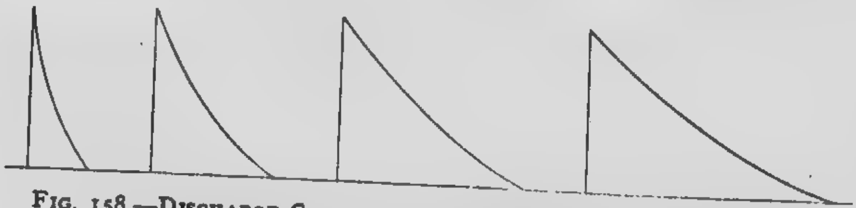


FIG. 158.—DISCHARGE CURVES OF CONDENSERS WHEN THEIR CAPACITIES ARE IN THE RATIOS OF 1, 2, 3, 4, WITH CONSTANT VOLTAGE AND CONSTANT RESISTANCE.

170. **Electricity as a Test of Death.**—The electrical reactions of muscle afford a complete test of death, as the contractility of the muscles only persists for a short time after death, and then disappears gradually.

If the muscles of a person supposed to be dead cannot be caused to contract when stimulated by the induction-coil current, life may be considered extinct ; on the other hand, if they retain the power of responding to this test, death, if it has occurred, must have been so recent that the inevitable changes have not yet had time to affect the muscles of the body. Certainly no person should be buried if his muscles are still normally contractile. The morbid fears of the public on the subject of the burial of persons not really dead could be completely allayed if this test were always applied before the certificate of death were signed.

Onimus and Legros* have shown that there is a stage in the dying of a muscle at which it gives the reaction of degeneration—that is to say, the irritability to the induction coil dis-

* "Traité d'Électricité Médicale," Paris, 1888.

appears first, while the response to direct battery current stimulation continues, giving rise to a sluggish contraction. This change sets in about four hours after death, and they relate a case in which the reaction enabled them to specify correctly the time at which death had occurred.

Marie and Cluzet,* who have recently repeated these experiments, have found that the muscular excitability disappears more or less quickly according to the nature of the disease which has caused death, and there may be differences in different individuals, but the reactions may begin to change after thirty minutes have elapsed since the time of death, and that a complete reaction of degeneration may make its appearance in one hour.

171. **Unstriped Muscle.**—The behaviour of unstriped muscle differs from that of striped in that its latent period is much longer, and the rate of contraction is also longer. When the muscular coat of the intestine is stimulated, it may contract locally, and remain contracted for a time, or waves of peristaltic contraction may start from the point stimulated and travel slowly towards the remoter parts of the bowel. It is said that the anode is the more effective pole for stimulating unstriped muscle. Unstriped muscle responds feebly to interrupted currents of brief duration, and the most effective means for setting up contractions in an organ containing unstriped muscle is to use the battery current, rhythmically interrupted at a slow rate (§ 72).

172. **Heart Muscle.**—The habits of heart muscle are peculiar in their highly developed tendency to rhythmic contractions. Electric stimulation tends to strengthen the action of heart muscle if it be timed to suit the natural rate of the rhythm. If the stimulation does not quite keep time with the heartbeat, it may effect a gradual change in its rate, until the heart may be brought to beat in time with the rate of the stimulation. If the stimulation be quite out of step with the rhythm of the heart, it will tend to embarrass its action. A weak continuous current or a smooth unbroken succession of weak induction-coil shocks may strengthen or accelerate the beat of the heart. Strong continuous currents destroy the rhythm of the heart, and cause it to stop in diastole (see below, § 178), and a succession of strong shocks from an induction coil do the

* *Archives d'Électricité Médicale*, 1899, p. 543; 1900, p. 285.

same. The useful employment of electricity to strengthen a heart which has suddenly developed signs of failure is very difficult, and there is considerable risk of doing the patient more harm than good by injudicious applications.

Dr. Hampson* has recently shown that rhythmic contractions set up in the large muscular masses of the limbs or trunk will modify the heart's rate, if the rate of the rhythm be arranged to be a little slower or a little faster than that at which the heart is beating. The effect is to propel blood from the muscles during the periods of muscular contraction, and this rhythmic propulsion of blood along the veins to the heart gradually influences the heart to keep time with the venous pulse so set up. This action of rhythmic contractions is to provide a sort of auxiliary heart mechanism, and it has proved useful in treatment.

173. **Sensory Nerves.**—The stimulation of sensory nerve endings or nerve trunks by electrical currents produces sensations. In the case of direct current a sensation of shock is felt when the current is closed and opened; but there is also a stinging sensation during the whole time of the passage of the current, unless this be very weak. This stinging sensation is undoubtedly due to the ionic movement set up in the cutaneous sensory nerve endings. It varies with the constitution of the saline solution with which the electrodes are moistened; for instance, if these are moistened with sodium carbonate, the stinging sensation is severe at the negative pole where CO_3 ions are penetrating; if sodium chloride be the medium, the sensation is felt most at the positive pole, where the sodium ions are entering. Chlorine ions cause relatively less sensation. and as this is also the case with ammonium ions, it follows as a practical point that ammonium chloride is a very good salt to use in solution for moistening electrodes.

A very complete account of the sensations which accompany the introduction of various ions is given by Dr. Sanchez,† in his essay on ionization.

A single discharge from an induction coil produces a sensation or shock like that felt at the make or break of a battery current, the severity of the shock depending upon the electromotive

* Proceedings of the Royal Society of Medicine, vol. v., 1912 (Electro-therapeutic Section), p. 119.

† "La Théorie des Ions en Électricité Médicale," A. Dugas et Cie, Nantes, 1902.

force and current in the circuit. An induction coil with its contact-breaker in action produces a series of shocks in which the individual impulses may be perceived, unless they follow one another too rapidly. At fifty interruptions per second the sensations begin to become fused, and at higher rates of vibration the sensation feels more smooth or continuous than before.

With rapid vibrations of one hundred per second and upwards, a benumbing effect becomes noticeable, and this is best felt if the electrode be applied to a point upon the trunk of a cutaneous sensory nerve. With a small displacement of the electrode away from the nerve trunk the numb feeling may disappear. It affects the area of distribution of the sensory nerve, and is a true anæsthesia, both tactile sensations and the perception of painful impressions being very greatly blunted while the current is passing, and a glow accompanied by perspiration often succeeds when the current is cut off. This procedure has been used to produce local anæsthesia for minor operations on the extremities.

If an electrode be moved over the surface of the skin systematically the position of the cutaneous nerves can often be exactly localized by this effect. One should use a very small electrode and a current which can just be felt, and whenever the electrode comes close over a nerve trunk the sensation of numbness in its sensory area at once becomes quite plainly felt, for it appears that a nerve trunk is more sensitive to the stimulation than the nerve endings are. In testing muscles it is of advantage to know the position of these "sensory points," in order to avoid them. On the dorsum of the foot there are several, which are apt to become painfully stimulated when testing the electrical reactions of the interosseal muscles. A little exploration of one's own cutaneous surface affords the best way of learning the position of these superficial nerve trunks.

Much fresh light has lately been thrown upon the sensory nervous system by the investigations of Dr. Henry Head.

In the Marshall Hall address to the Medico-Chirurgical Society in 1905, Dr. Henry Head, F.R.S., gave an account of certain investigations carried out by him in conjunction with Dr. W. H. Rivers and Mr. James Sherren. In the course of these studies he had an interesting experiment performed on his own arm. The cutaneous branch of the radial nerve was cut, and the process of return of sensation after the injury was carefully watched.

He found as a result of this experiment, confirmed by a large

number of examinations of other peripheral nerve injuries, that ordinary touch sensibility included at least two types of perception. Recovery of sensation after complete division of a peripheral nerve begins with disappearance of the analgesia, and with the return of sensation to the extreme forms of temperature, but for a time the hand remains exactly as insensitive as before to the lighter stimuli, such as light touch. The characteristics of a part which has again become sensitive to pricks and to the extremes of heat and cold are : (1) The sensation radiates widely, is referred to remote parts, and cannot be accurately localized ; (2) a prick produces a more unpleasant sensation than over normal parts ; (3) the sensation produced gives no measure of the intensity of the stimulus by which it has been evoked. In order to distinguish this form of sensibility, Dr. Head has assigned to it the name "protopathic." With further recovery a second form of sensibility appears. This is associated with accurate localization of cutaneous stimuli and the discrimination of two compass points. With the return of this form of sensation light touch and intermediate degrees of heat and cold can be again appreciated. This form of sensibility should be called "epicritic."

Protopathic and epicritic sensibility probably depend each on a separate system of nerve fibres for the following reasons: (1) Occasionally, after division of a peripheral nerve, sensibility to pain, to ice, and to 50° C. may be abolished, but that to light touch and to warmth at 40° C. remains. (2) After complete division of a nerve protopathic sensibility returns before epicritic, whereas after functional division (incomplete destruction of the nerve) the two forms of sensation return *pari passu*. A part deprived of its nerve supply is liable to injuries, and the sores and ulcers so produced heal slowly. Such sores heal rapidly and permanently as soon as protopathic sensibility has returned to the part, even though all epicritic sensation is still absent. A third form of sensibility was also detected. After the radial half of the arm and back of the hand had been rendered totally insensitive to cutaneous stimuli, these parts of the hand remained sensitive to pressure or to any stimulus that deformed the subcutaneous structures. The power of localizing such stimuli as could be appreciated was not lost. The fibres upon which this form of sensibility depended must therefore run with the motor nerves, and supply the muscles with sensibility.

This was called "deep sensibility." The sensation of shock is probably largely felt by these fibres. When a muscle is tetanized the sensation is one of a dull ache felt in the "deep sensibility" fibres and an "ionic" sting in the protopathic fibres of the skin under the electrode. Every peripheral afferent nerve of the limbs probably contains both protopathic and epicritic fibres. Towards the periphery the latter tends to fall into certain groups, and the area supplied by each group does not overlap that of another group materially. The protopathic fibres, on the contrary do overlap to a considerable extent at the periphery of the limb. This overlapping becomes less as the posterior roots are approached, showing that these fibres still maintain to a certain extent their segmental arrangement. The threefold arrangement of deep, protopathic, and epicritic sensibility ceases in the central nervous system at the first cell junction. The impulses conducted along these three lines become sorted out into paths for light touch, for localization and stereognosis, for pain, for heat, and for cold.

Observations on the application of temperature stimuli to the intestine seemed to show that its sensibility resembled that which, in the skin, had been called protopathic. But it was entirely insensitive to all those stimuli which evoked epicritic sensation. Consequently, Head has suggested that the body within and without is supplied by afferent nerves which belong to the protopathic system. This can be divided into somatic and splanchnic, the latter including all that has previously been known as the afferent sympathetic.

The protopathic system is peculiarly associated with the reflexes and with feeling tone (pleasure and pain). The sensations evoked from it in answer to appropriate stimuli are widely diffused, and are not infrequently referred to parts at a distance. Its fibres regenerate with greater ease and rapidity than those of the epicritic system, or those of the motor nerves to voluntary muscle. This system retains to a considerable degree its original segmental arrangement.

The external surface of the body and limbs is innervated by a second system of fibres—the epicritic. This system is of later development, and regenerates more slowly than the protopathic. It is peculiarly associated with the localization and discrimination of cutaneous stimuli.

All subcutaneous structures are also innervated from afferent

fibres that end in sense organs peculiarly susceptible to pressure. These fibres in the limbs and body wall run in conjunction with the motor nerves to voluntary muscles, and this "deep sensibility" is not materially diminished by the destruction of the sensory nerves to the skin (see *Brain*, Part 110, Summer, 1905).

A marked difference exists between protopathic and epicritic nerve fibres in their response to interrupted currents, for the former appear to be unaffected by impulses whose duration is less than about 0·002 of a second, and consequently current waves having that duration or less produce a stimulation which is nearly devoid of painful impressions, though they are still felt as a succession of impulses through the agency of the epicritic fibres.

174. **Nerves of Special Sense.**—The nerves of special sense respond to electrical stimulation by their own special sensations; thus stimulation of the olfactory nerve endings is said to produce a smell "like phosphorus," stimulation of the auditory nerve endings give rise to the perception of a sound, stimulation of the semicircular canals produces vertigo, and stimulation of the retina produces the impression of a flash of light. Some observers have even thought that the colour of the retinal effect seemed to depend upon the direction of the current, kathodal closure giving a reddish colour and anodal closure a bluish one. The retina may be stimulated with one pole at the nape of the neck, and the other over the closed eyelid. In making experiments on the eye, one may well bear in mind the accident which befel Duchenne, who apparently caused serious damage to the vision of a patient when applying a current to his face. The effect may have been a retinal hæmorrhage caused in some way by the electrical application.

Duchenne observed that the current of the secondary coil acts on the retina more strongly than that of the primary, and this may now be explained by the longer duration of the waves in the former case. Waller* has also observed that longer stimuli are better adapted to the excitability of the retina, and shorter stimuli to the excitability of common sensory terminal organs. The optic nerve seems to behave like a protopathic nerve in this respect. The influence of wave length upon the retinal effect can be readily observed with the Leduc interrupter by changing the wave lengths while the machine is running.

* Proceedings of the Royal Society, July 27, 1899.

The auditory nerve endings also respond to stimulation by the battery current, with the perception of a sound, best heard at kathodal closure, but also heard less plainly at anodal opening. It is variously felt as a hissing, or whistling, or humming sound, and is not very easily excited in normal individuals, but is readily felt in certain conditions of increased irritability of the auditory apparatus.

Stimulation of the auditory nerve also sets up certain other reactions, which have been studied by Babinski. One of these is the voltaic vertigo, and the other is the voltaic nystagmus. These have been fully described by Weill and others,* assistants in Babinski's clinic.

The voltaic vertigo is an inclination of the head to the side of the anode; it is generally produced by a current of 1 or 2 milliampères, and is accentuated when the current is increased. It is not a momentary occurrence, but persists with the passage of the current. A sensation of giddiness is felt which may cause the patient to fall over, especially if tried when he is standing up. When the current is turned off, the head resumes its proper position, slowly or suddenly, as the current is turned off slowly or suddenly.

To observe it the electrodes should be placed, one on each side of the head, just in front of the tragus, and should be kept in position by an elastic band. The patient may sit up or may stand upright, but the former is the more convenient. If the electrodes are asymmetrically placed, with the kathode below the lobule of the ear, the movement is partly one of rotation of the head upon its axis.

The voltaic nystagmus is a phenomenon associated with the voltaic vertigo. The authors of the paper from which this account is quoted state that the nystagmus is less valuable than the vertigo as a diagnostic sign. The nystagmus is generally rotatory, and consists of sudden rotatory movements of the eyeball towards the kathode. It is a phenomenon less constant and less easy to produce than the voltaic vertigo, and requires a current of 3 or 4 milliampères.

The exploration of these auditory reactions is disagreeable to the patient, and should be completed as quickly as possible, otherwise headache and vomiting may be set up.

Abnormality in the reactions implies alterations in the semi-

* *Archives d'Électricité Médicale*, June 25, 1911.

circular canals. If the semicircular canals of one side are devoid of function, the inclination of the head takes place only to the side which is sound, whatever the direction of the current. If the semicircular canals of both sides have lost their function, the voltaic vertigo does not appear.

The gustatory nerves react to currents by a sensation of taste, often described as an acid or metallic sensation. Heümann* has described some experiments which seem to show that this taste is felt at that part of the tongue towards which anions are moving, and that the anion concerned is the hydrogen anion of the acid saliva. He caused the current to traverse the head in various directions, and observed that the taste was most noticed at the surface of the tongue nearest to the anode. He also took an apple and peeled it at one point. Then, inserting a needle connected to the positive pole into the apple, and holding the negative pole of the circuit in his hand, he brought the peeled surface of the apple into contact with his tongue. The acid taste of the apple was intensified as compared with its taste when no current was passing. When the current was reversed, so as to pass from the tongue to the apple, the acid taste seemed to be greatly reduced.

Similarly, a wire armed with cotton and moistened with solution of sulphate of quinine tasted more acid and bitter than usual when made the anode of a circuit passing through the tongue, because the current assisted the penetration of the hydrogen and quinine ions.

175. **The Brain.**—Experimental physiologists have made much use of electrical stimuli in determining the situation of motor centres in the exposed cerebral cortex. In ordinary electrical applications it is found that when a continuous current is passed transversely through the skull, with the electrodes on the temples or mastoid processes, the most prominent effects are those produced upon the auditory apparatus which have just been described. There is no visible stimulation of the motor areas, either with interrupted or with continuous currents, and it has been said that they do not penetrate the skull, but this is certainly an error. It is quite easy to produce certain cerebral effects with direct currents, and the resistance of bone is not greater for interrupted currents than for direct currents. Some other explanation is therefore necessary for the absence of effects

* *Archives d'Électricité Médicale*, April 10, 1911.

with interrupted currents. Owing to the spherical shape of the skull, diffusion of current is favoured, and therefore the density of current is greatly lowered at a short distance away from the electrodes. For this reason, the stimulation becomes evenly divided over the whole of the area between the electrodes, and the effects produced are likely to be effects of stimulating the brain as a whole rather than those of stimulating any small part of it.

Moreover, the skin of the head is very sensitive to induction-coil currents, and the applications soon become very painful if the currents are strong, and this prevents close observation on the part of the person experimented on.

Battery currents produce effects upon the brain which can readily be perceived, although stimulation of the motor cortex has not been accomplished. Leduc has made many experiments upon the application of electric currents to the brain, and he states that he has been able to recognize the successive production of aphasia and of motor paresis by the inhibitory influence of continuous currents applied to himself, with the negative electrode on the forehead.

He has also described the condition known as "electric sleep," produced by intermittent currents sent longitudinally through the brain, and also a whole series of other peculiar phenomena,* such as astasia, ambulatory automatism with psychic blindness, phototropism, acceleration and slowing of respiration, states of lethargy and of catalepsy, loss of memory, and epilepsy.

176. **Electric Sleep.**—Leduc has published an account of some remarkable effects produced by rapidly interrupted currents passed longitudinally through the nerve centres.† The anode was placed on the hinder part of the back of a dog or a rabbit, and the kathode on the skull. The skin was previously shaved. The current was increased gradually, and at a certain strength the animal became unconscious. When this stage was reached, a state of tranquil sleep was induced, in which the animal remained until the current was stopped. During this period of sleep there was anæsthesia. As soon as the current ceases the animal jumps up and seems quite well, and no injurious results follow.

* "Études d'Électro-psycho-physiologie," *Arch. d'Électricité Médicale*, December 25, 1908.

† "Le Sommeil Électrique," Paris, Masson and Co., 1907.

Robinovitch* has also published an account of researches conducted in Leduc's laboratory upon the phenomena of electric sleep. This account of a very interesting phenomenon gives full details of the precautions necessary for ensuring the safety of the animal during the production of sleep, which can be established and maintained for several hours without harm to the animal. It also gives an account of an experiment in which Professor Leduc was himself the subject, but in which the current was not pushed to complete insensibility, the operators believing that this had been attained, although the Professor was able to tell them afterwards that consciousness had not been lost, though he was quite unable to communicate with them on account of his peculiar condition, which he compares to that of one in a nightmare, aware of some impending disaster, but unable to move or cry out. The current used in these experiments is the Leduc current (§ 63), with 100 periods a second, and with closures of one-thousandth of a second. The application of this electric sleep to practical medical purposes remains untried, but it seems possible that it may one day prove useful. There only remains the difficulty of finding some patients to put to the test. Extreme care is needed to secure regularity of the current, which should for this reason be drawn from accumulators, and not from the mains, because irregularities, even slight ones, produce perturbations in the sleep, and may determine arrest of respiration or of the heart. The usual voltage for rabbits is five or six volts, and the mean current registered on the milliampèremetre one milliampère, which is the equivalent of ten milliampères during the actual time for which the current is running.

If the voltage employed be much higher, and the intermittent current be closed suddenly and opened after four seconds, the animal passes into an epileptic seizure of typical character a few seconds after the rupture of the current. Gouin† has written on this subject, and has considered the influence of various drugs in modifying the character of the epileptic seizure produced by the current. He finds that cocaine, chloroform, and chloral suppress the development of the seizure, and that of these chloral acts most advantageously. Bromide of potassium was

* "Sommeil Électrique: Épilepsie Électrique et Électrocution," Nantes, A. Dugas and Cie, 1906.

† "Étude de l'Épilepsie Expérimentale," Nantes, A. Dugas, 1904.

almost without effect, and strychnine increased the severity of the seizure [illegible] slight degree only.

177. **Thermal Effects of Currents.**—It was stated in § 22 that when a current flows through a conductor, energy is absorbed in overcoming the resistance, and the conductor becomes heated. This applies to all conductors, and the body is therefore heated whenever a current passes through it. With currents of the magnitude ordinarily employed in medical treatment the heating effect is inappreciable, but it becomes evident when the large currents of high frequency are used, and in the form of high-frequency apparatus described in § 138 (Diathermy) the heating effects become conspicuous.

It is interesting to note that the heating effects of ordinary high-frequency currents were for a long time ignored, although they were observed in 1896 by D'Arsonval. They were, so to speak, rediscovered by Somerville,* who pointed out that there was a rise in the surface temperature of a limb submitted to the action of high-frequency currents.

The ordinary unipolar application of the high-frequency apparatus on the condenser couch gives currents of 500 milliampères or a little more. When, as is the case with the diathermy apparatus, the current is raised to 1·5 or 2 ampères, the heating effects are naturally more marked, and with this instrument one can study the heating effects of electrical currents upon the body. It is quite probable that the action of high-frequency currents upon patients is chiefly a result of this liberation of heat in the tissues. The alterations of blood-pressure, of pulse-rate, of heat production, and of elimination of CO_2, may all be attributed to the warming of the tissues and the physiological response thereto. The general effects of high-frequency currents will be further considered in a succeeding section.

178. **Death from Electric Shock.**—The fatal effect of powerful currents is due, in most cases, to stoppage of the action of the heart, which falls into a condition of irregular fibrillar twitching, from which it seems unable to recover, and it soon stops altogether. The tracings (Figs. 159, 160)† show the results in some experiments upon cats under chloroform. In the first is seen

* "The Influence of High-Frequency Currents on the Surface Temperature of the Human Body," *Medical Electrology and Radiology*, May, 1906.

† Lewis Jones, "The Lethal Effects of Electrical Currents," *British Medical Journal*, March 2, 1895.

the rapid fall of blood-pressure to zero after the passage of a current of half an ampère transversely through the thorax. A current of the same magnitude through the skull produced a trifling effect, with increase of blood-pressure, which is seen in the first part of the same tracing. In the other figure is seen the secondary effect upon respiration, caused by the failure of the blood-supply in the respiratory centre. These tracings were

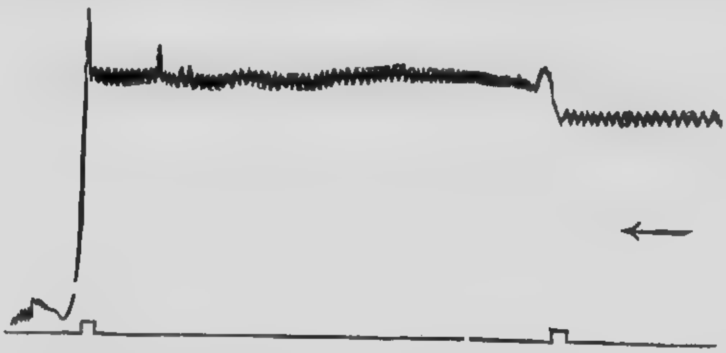


FIG. 159.—BLOOD-PRESSURE TRACING, SHOWING EFFECT OF ELECTRIC SHOCK THROUGH SKULL AND THROUGH THORAX OF A CAT.

taken during some experiments with the direct current. Oliver and Bolam have more recently published tracings showing that with alternating currents the results are similar. To cause death, the currents must have a certain minimal value, and must traverse a vital organ, the heart being the most susceptible.

Other most important researches upon the cause of death from electric currents are those made by MM. Prevost and Battelli,*

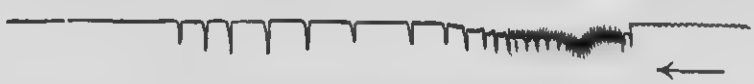


FIG. 160.—FAILURE OF RESPIRATION ATFER STOPPAGE OF THE HEART FROM ELECTRIC SHOCK.

and a valuable summary of their work will be found in the *Arch. d'Élect. Médicale*, 1902, p. 777, by Battelli. A very peculiar point is brought out in their researches—viz., that electric currents may kill in two distinct ways—that is to say, either by a direct effect upon the heart, like that shown in the tracings just given, or by an entirely different effect upon the central nervous system, causing an arrest of respiration, the beating of

* *Comptes Rendus*, March 27, 1899.

the heart remaining unaffected. Battelli states that with low pressures (small currents) death occurs, in the first manner, through the heart. Among animals certain differences of susceptibility are observed. In dogs, for instance, the arrest of the heart's beat is final and proves fatal; in guinea-pigs and in rabbits the heart's beat is arrested and fibrillar twitchings are produced, but the natural beating may be resumed. In rats an arrest with fibrillar twitchings is produced, but lasts only so long as the current is passing, so that in these animals the heart recommences to beat in a normal manner as soon as the current is switched off, and they are not killed through a stoppage of the heart. Strange to say, this effect of currents in arresting the heart is more evident with small than with large currents, and is not observed with very large currents, so that Professor Battelli actually states that a heart arrested by an electric shock of small magnitude can be caused to recommence beating by a current of large magnitude sent through it afterwards. When the currents are large, it is the central nervous system which is the most affected; consequently, in cases of accident from contact with high-pressure conductors, and when large currents have traversed the patient's body, the heart-beat may not be arrested, but there may be a profound inhibition of the respiratory centre. As the arrest of respiration is not inevitably fatal, but may be recovered from, either with or without the help of artificial respiration, it follows that beyond a certain point danger is decreased rather than increased with increase of current through the body. If this view is correct, it will explain some of the surprising non-fatal accidents which have happened of late years with very high-tension currents.

The views of D'Arsonval that electric shocks prove fatal by arrest of respiration are thus seen to be correct in certain cases only. It is probable that the fatal accidents are generally cases in which the heart has been arrested, while the severe but non-fatal cases have suffered through shock to the nerve centres, with temporary arrest of respiration, while their hearts have escaped.

In the absence of direct observations, the minimum fatal current for human beings may be estimated at about one-half to one ampère. The most common path of the discharge is from one conductor to earth through the body, but the current may also pass directly from the body to the other conductor of the

system. In the first case the point of exit is generally by the feet. Burns of the skin should always be looked for at the points of entry and of exit; they may be severe or slight. When the current goes to earth through the feet, these may not show signs of burning if the foot covering is damp. The severity of the burns is proportional to the voltage of the circuit and to the duration of the discharge. The higher the voltage, the more quickly is a burn produced. Many of the fatal accidents have been with potentials above one thousand volts, but a number of cases are on record of death from contact with circuits of 200 volts, and some at even lower pressures.

The lowest recorded voltage which has caused death seems to be 96 volts, in a case mentioned by Jellinek of Vienna, and occurring in a factory at Prague to a man whose boots were wet with a solution containing potash salts, and therefore conducted freely. A man was killed in South Africa by 110 volts, alternating. The live wire had fallen to the ground, and the man took hold of it to pull it to one side, and, receiving a shock, fell into a gutter of running water. People, hearing his shouts, ran to his assistance, but by the time he was freed from the wire he was dead. Those who went to help him also received shocks.

When people have been killed by pressures of 200 or 220 volts, in almost all cases they have been in good connection by their feet with water or damp ground, and the discharge has been to earth.

The subject of accidents from electric light circuits is well dealt with in Jellinek's "Atlas of Electro-Pathology." This work has many coloured illustrations of the actual surroundings and appearances in a series of fatal cases observed by the author.

Experience has shown that the body may carry a current sufficient to produce extensive burning at the points of contact, without causing death, and this may be the case even when the current has fairly traversed the trunk. In an accident in London two men were concerned, and the current passed from the live conductor to the first man, and from him through the second to earth. The first man survived, though the second was killed. In three other cases which I have had under my personal observation men have been traversed by currents sufficient to cause very serious burns on circuits of 2,500 alternating and have survived. The relative danger of alternating and direct currents is not decided; the latter appears to be the more dangerous.

Battelli considers that when alternating currents are concerned there is diminution of danger with increase of frequency, and it certainly appears that alternating currents of low periodicity are dangerous even at low voltages.

In some cases persons have survived the actual shock, to die later from extensive destruction of the whole thickness of the tissues of a limb or limbs. Here the phenomena are almost certainly phenomena of heat coagulation from the conversion of the current into heat in the tissues. Lucas* has reported a case of this kind in which the patient, a boy of fifteen, received a shock from the 10,000 volts main, but recovered consciousness, and was taken to the hospital. The extremities were pulseless and in a state of solid œdema. Gangrene followed. Amputations were performed; the arterial trunks were found to be thrombosed, and the patient died on the ninth day after the accident.

As artificial respiration may restore people who have been apparently killed by electric shocks, provided that there has not been a definite stoppage of the heart, this procedure should always be tried; and mention may here be made of an apparatus designed to facilitate artificial respiration, called the "Synchron" life-saving apparatus.† It consists of a board, upon which the patient is laid, with a pair of hinged levers working together at one end of it. To use it the levers are strapped to the patient's wrists, and when they are moved they ensure that the respiratory movements given to the arms in the process of artificial respiration shall synchronize properly. All that is necessary to do is to raise and lower the levers slowly and regularly—that is easy, and ensures a good inspiratory and expiratory movement.

* Clinical Transactions, 1905.

† The Synchron Co., 11, Serjeant's Inn, London, E.C.

CHAPTER X

GENERAL THERAPEUTIC CONSIDERATIONS

Chemical and physical basis of electrical treatment—Stimulating and trophic effects—Ionic medication—Thermal effects of high-frequency currents—Effects of statical treatment—Effects of X rays—Effects of radium—Phototherapy.

179. **Chemical and Physical Effects of Currents.**—When we come to consider the medical applications of electricity, we must begin with clear ideas of the effects which can reasonably be expected on physiological grounds, and must then proceed to inquire as to the best methods to be followed for obtaining the results desired in any given case.

Reduced to first principles, the effects of electrical currents upon the body are the results either of ionic movement or of heat production, and we have to consider the various events which may follow, either directly or indirectly, from one or other of these physical phenomena, and the best way of applying them in the treatment of disease.

It is unnecessary to consider any mysterious "vital" effects of electricity, nor need we waste time over the notion that electricity cures through its effect upon the imagination. It is true that cures can be wrought in functional disorders by making use of electricity to terrify or to hurt, or in some other way to impress the minds of the subjects to whom such applications are given, but all that kind of business occupies a place apart from the genuine practice of electro-therapeutics, which is based solely upon chemical and physical considerations, and does not require the assistance of the imagination of the patient.

180. **Stimulant and Trophic Effects.**—The most general of all the actions for which electricity is used is that of stimulation of the functions or the tissues of the body, and especially of the nervous and muscular tissues.

There still exists a widespread notion that electricity is useful

only for the stimulation of paralyzed limbs, and this belief has tended in the past to limit the scope of electro-therapeutics, and to interfere with its progress. But although the use of electricity in motor and sensory paralysis is an important one, the stimulating effect of electrical currents in other conditions is also of great utility, so that we find it used with great advantage as a general application to the whole body for its "trophic" effects in states of general debility or of defective nutrition, such as anæmia, rickets, obesity, rheumatism, gout, etc. Its stimulating action upon the peripheral circulation is evident from the rapid good effects which it produces in chilblains, and in promoting the absorption of effusions into joints and serous cavities.

Many kinds of electrical application produce stimulating effects. Interrupted currents, such as those of the induction coil, and the sinusoidal dynamo current, influence especially the nervous and muscular apparatus by setting up small but sudden and frequently repeated ionic displacements. High-frequency applications stimulate by the production of heat in the parts through which the current passes, and therefore act especially upon the vasomotor mechanisms. The spark and brush discharges of the static machine and of high-frequency apparatus stimulate through the cutaneous sensory nerves chiefly by minutely localized heating effects.

D'Arsonval, who examined the trophic effects of electrical applications of various kinds, has shown that induction-coil currents, by producing more or less extensive muscular contractions, augment the oxidation processes of the body, but that even when so gentle as to cause no muscular contraction they can nevertheless cause modifications in the nutritive exchanges of the body with increased production of heat; and that the sinusoidal current acts similarly and produces a more marked effect. By its use the respiratory exchanges can be augmented by 25 per cent., and that without provoking any muscular contractions whatever. This result is found both in men and in animals.

Experiments were made by Dr. Beard* to determine the effect of "general faradization" upon the growth of young dogs, and they were kept under treatment for four weeks, being treated daily with an induction-coil current; at the end of the time the two animals which had been so treated had gained in weight

* Beard and Rockwell, "Medical and Surgical Uses of Electricity."

faster and were perceptibly bigger than two others which had been kept untreated as control animals.

Debedat* made a series of experiments on the muscles of young rabbits with various kinds of electric applications. The group of hamstring muscles was chosen; those of the left side were stimulated in various ways daily during twenty days, for four minutes a day; those of the right side were left for purposes of comparison. At the end of the period the animals were killed, and the muscles of the two sides carefully removed and weighed; portions were also examined microscopically. The modes of stimulation were as follows: (1) The induction-coil current with rhythmic periods lasting for one second, and followed by one second of interval, and so on for four minutes; (2) the battery current of two milliampères, with the same periods of stimulation and repose; (3) electrostatic sparks, two or three millimetres long, repeated every two seconds for the same periods; (4) tetanization of muscle for four minutes, by means of an induction coil without any intervals of repose; (5) steady battery current for four minutes, without any intervals of repose.

The results showed a gain of forty per cent. in weight on the stimulated side with the rhythmic induction shocks, and of eighteen per cent. with the rhythmic battery current. The sustained tetanization caused a marked loss of weight; the sustained steady battery current caused a slight increase in weight. The gain in weight was due to a true growth of the muscle; the loss was accompanied by histological evidence of damage to the muscle fibres. The static sparks had no visible effect. The author concludes that for promoting the growth of muscle by electricity the current should be interrupted, and the periods of contraction and repose of the muscle should be arranged so as to approximate to the conditions of a muscle during the performance of rhythmic gymnastic movements, with about thirty periods of contraction and thirty intervals of rest per minute, prolonged tetanization being hurtful.

H. Bordier† has made experiments of the same kind on a healthy human being, and has shown a direct result upon the growth of muscle from electrical stimulation. He made use of a combined "galvano-faradic" current interrupted rhythmically 30 times a minute, with intervals of one second. The

* *Archives d'Électricité Médicale*, February and March, 1894.

† *Ibid.*, 1902, p. 331 (with illustrations).

biceps, brachialis anticus, supinator longus, and the extensors of the wrist of one side, were stimulated on alternate days for periods of ten minutes. After two months the parts were measured, and compared with measurements which had been carefully taken before treatment was begun. The increases were as follows: Girth at centre of arm, 2·7 centimetres; at lower third, 2·3 centimetres; of forearm, 2 centimetres below fold of elbow, 2·3 centimetres; at 5 centimetres lower down, 2 centimetres.

181. **Modes of Application.**—When it is wished to produce a general stimulation of the whole body, the electric bath provides one of the best methods. The source of current should be either an induction coil or the alternating mains, using a transformer and a rhythmic interrupter.

The apparatus used for the electric bath has been described in § 70. For the administration of the bath the procedure should be as follows: The current should be turned on to half strength before the patient enters the bath, and the circuits tested, the strength of the current being gauged by feeling it with the hands immersed at the two ends of the bath.

The patient, after entering the bath, should sit up for a minute or so to become accustomed to the sensations produced by the current, and this should be increased slowly and cautiously.

With the sinusoidal current 30 or 40 milliampères are generally sufficient. With induction-coil currents the strength should not be so great as to make the patient's muscles rigid.

After the bath the patient should dress slowly, in order to allow the activity of the circulation in the skin to diminish during the process of dressing. If the patient dresses hurriedly while the skin is perspiring, he will feel damp and uncomfortable, and will run the risk of taking a chill. With due care there is very little danger of cold after an electric bath.

The duration of the bath should be for ten or fifteen minutes, and they may be given on alternate days. Twelve baths should produce signs of a good result if the treatment is going to prove useful, but in many chronic states more than this number will be wanted.

It is usual for patients to feel tired and inclined to sleep after an electric bath, and it is as well to tell them of this beforehand, or they may take it as an unfavourable sign.

In all electric bath treatment the utmost care must be taken

with the conducting circuits and the regulating apparatus. Any defects at the connections, at the binding-screws, or elsewhere, must be guarded against. The patient in the water is helpless, and easily becomes alarmed at the occurrence of anything unexpected in the way of sudden changes in the flow of current, and he may consider it to be dangerous to come for any more treatment if he has once received a disagreeable shock. On this account it is recommended always to make a trial of the entire bath circuit at the last moment and to have the current flowing before the patient steps into the water. When the patient is already in the bath, there should be no hitch. See also § 93 for the precautions to be adopted to ensure safety in electric baths supplied from the mains. A case has lately been reported where a patient was killed while taking an electric bath connected to 240-volt mains and unsuitably protected.*

The four-cell bath of Dr. Schnee, and the arm bath (§§ 68, 69), are also very convenient modes of applying electricity for the stimulation of the limbs, and the current which is suited for the full-length bath should be used in these also.

For local stimulation the current may be applied with ordinary moistened electrodes (§ 67). If a rhythmic interrupter is available, the electrodes should be attached by straps or bandages to the part to be treated, so that the current will traverse the affected area ; or in default of a rhythmic interrupter, the desired variations of current may be produced by using an electrode with a handle for the active electrode, which the operator will move backwards and forwards over the affected area during the time of the application. The first method is the best.

A form of general stimulation applied chiefly to the nerve centres has been proposed by Beard and Rockwell, under the name of "central galvanization." Direct current is used. It consists "in placing the negative pole at the epigastrium, while the positive pole is applied to certain parts of the head, especially to the forehead and vertex, to the sympathetic and pneumogastric in the neck, and down the whole length of the spine from the first to the last vertebra." It is said to be useful in cases of hysteria, neurasthenia, sleeplessness, dyspepsia, and other complaints. The duration of each application may be for ten minutes, the strength of current ranging between five and ten

* "The Need for Supervision of Electric Bath Establishments," *Electrical Engineering*, November 14, 1912, p. 638.

milliampères, according to the part under treatment, and being reduced a little for the applications to the head.

Leduc has also insisted on the beneficial stimulant effect of direct currents applied to the brain, in a longitudinal direction. Interruptions and variations of current are to be avoided, as their action is disagreeable, while the brain seems to respond better to steady currents. The effect is probably due to the ionic interchanges which are set up.

Armstrong* advises the use of currents of one to five milliampères for the head, and up to twenty milliampères for the spine, with applications for ten to thirty minutes repeated three or four times a week, or daily. He quotes cases in which he obtained good results in palpitation and irregular action of the heart, in conditions of cerebral exhaustion, and in neurasthenia. With currents of too great strength, or too abruptly made and broken, unpleasant effects may follow, especially in the applications to the head.

Electrical applications to the nerve centres will probably be found useful in many cases of the kinds just mentioned. Capriati's experiments (§ 185) with healthy individuals have shown that the application of currents of ten to fifteen milliampères to the spine for ten minutes produces a marked effect upon the muscular power.† This favourable effect is commonly observed with patients under treatment.

The simultaneous use of the continuous and the interrupted current has been recommended. The method consists in connecting together the secondary circuit of an induction coil and a direct-current battery, by joining up the negative pole of the one with the positive of the other, so as to send both currents together through the body. It was thought that the effects of the interrupted current were enhanced by a simultaneous galvanization. Dr. de Watteville had a high opinion of the advantage of this mode of treatment, particularly for electrization of the abdominal viscera, in rheumatic conditions, and in atrophic paralysis. The method is still occasionally used.

182. **Ionic Effects.**—The effects of stimulation are best obtained by working with varying currents, as we have just seen (although the brain and perhaps the spinal cord may be excep-

* Transactions of the Royal Medical Society of London, vol. xxi.

† "Influence de l'Électricité sur la Force Musculaire," *Arch. d'Électricité Médicale*, November, 1899.

tions). On the other hand, the effects of ionic movement require currents flowing steadily in one direction, because the movement of ions is slow, so that a long and strong impulse is needed to produce appreciable ionic changes in a part submitted to treatment, and because any reversal of the direction of the current tends to reverse the effect.

The ionic or chemical effects of currents may be subdivided as follows: (1) Displacements and rearrangements of the ionic constituents of the tissues; (2) introduction of drugs from without; (3) destructive electrolytic effects at the junctions of the metallic and electrolytic portions of the circuit.

183. **Ionic Displacements.**—The influences of the ionic movements which are set up in the deeper tissues by the passage of a current are difficult to estimate. But there is no doubt that interchanges occur between different tissues. It is only necessary to recall to mind the abundance of phosphates and of potassium in the nervous tissues, in muscle, and in the red blood-corpuscles, and the abundance of chlorides, of carbonates, and of sodium in the plasma and lymph, to see that numerous opportunities must occur for alterations of chemical composition to be produced when currents traverse these parts. Many effects formerly not understood, and therefore spoken of as alterative or catalytic effects of electricity, may justly be attributed to deep ionic exchanges, and the more so that these effects can now be obtained with more certainty when the electrical treatment is so given as to ensure the maximum of ionic displacement in the affected area. The successful employment of direct currents of large magnitude, and for long times, in strains of muscle, in sprains of joints, in muscular rheumatism, in cases of ankylosis and fibrous thickenings, suggests the influence of chemical interchanges occurring in the depths of the tissues as a result of the ionic movement. As a result of the teachings of Leduc on the subject of the ions in medicine, we have learnt how to apply large currents without pain or damage to the skin, and in learning that we have gained notably in our power of giving relief or cure in many conditions of disease.

184. **The Introduction of Ions from Without.**—The practical employment of ions in medication is mainly due to the writings of S. Leduc, who has advocated this method, and given detailed instructions as to the mode of procedure in a series of admirable papers, which have yielded valuable results in medical practice.

By the use of electrical currents the active ions of many compounds can be introduced into the skin and the subcutaneous tissues, or into the floor of an ulcer, or the walls of a sinus. We do not know precisely how deeply we can introduce ions in effective quantity, but we do know that for superficial morbid conditions the introduction of an appropriate ion produces an immediate good effect. The following passages, translated from one of Leduc's papers,* give us information about the three valuable ions, zinc, salicylic acid, and chlorine, which have useful medical properties.

"Of the heavy metals, there are many whose ions are more or less caustic, probably because they coagulate albuminous substances, but the one which is of most interest from a medical point of view is the ion of zinc. This ion is an antiseptic of the first rank, and there is no wound or ulcer which cannot be disinfected by its employment, provided its surface can be reached by the electrodes. One of its peculiarities is that it provokes but little inflammatory reaction. When I have experimented with zinc upon the skin of animals, and have caused superficial or even deep ulceration, I have observed that the wounds produced show no inflammatory effect or sign of infection from germs, even if they are left completely uncovered; on the contrary, they remain aseptic, so that it appears as if the ions of zinc which they contain serve as the best possible of antiseptic agents. Zinc ions should be used in the treatment of chronic ulcers, sinuses, or fistulæ, the method being far preferable to curettage, which manifestly incurs risks of setting free infective agents, and of admitting them into the blood and lymph channels of the part operated on.

"Some of the more complex ions of organic compounds can also be made use of in electrolytic applications, as, for instance, adrenaline, cocaine, and others. Anæsthesia of the surface can be produced in five minutes with cocaine with a current of small density, but its practical employment in this way requires discrimination, because irritation of the skin is apt to follow, with a brown discoloration, which may persist for a considerable time. It is interesting to note that cocaine introduced in this way diffuses away very slowly from the point where it is introduced.

* "Les Ions en Médecine," *Archives d'Électricité Médicale*, Sept. 25, 1904. "Electric Ions and their Use in Medicine," Rebman, London.

"Salicylic acid is another body whose ions seem well tolerated by the tissues. Very little local inconvenience follows its introduction. I have used it successfully in the treatment of dry pleurisy. A large pad soaked in a two per cent. solution is applied to the whole of the affected region, and a current of 100 milliampères is caused to flow for half an hour. After the application the skin has a uniformly red appearance, but in almost every case in which I have tried this remedy the pain and the shortness of breath have disappeared, and the patients have declared themselves more benefited than by any other kind of application.

"Other writers have demonstrated the good effect of the salicylic ions in cases of chronic rheumatism.

"Chlorine ions seem to have a marked effect in producing resolution of scar formations and stiffened tissues. By means of them stiff joints can often be rapidly cured without the need for painful wrenching movements, and under the electrolytic treatment one can see the stiffness disappear gradually from day to day, and the affected joints recover their original power of movement. This result has been noted by myself on many occasions. It is of primary importance that the disease which originally produced the stiffness shall have disappeared, and that no active inflammatory process be going on at the time of the treatment. The best procedure for obtaining this softening of scar tissue is to use a one per cent. solution of common salt as the electrolyte, and to apply the cathode to the affected region under this pole. The tissues receive chlorine ions and part with the ions of sodium, and these exchanges seem to modify the chemical constitution of the tissues in the way best adapted for the softening of adhesions and cicatricial tissue. I can quote a case where a stiff wrist of six months' standing, the result of phlegmonous inflammation, had resisted many kinds of treatment, including forcible movements under an anæsthetic, but recovered free movement after two applications of the electric current. Cases of stiff knee have also, in many cases, become quite free after a few applications of this method. The more accessible a joint is, the more easily the results are obtained, and for this reason greater difficulty is found in the treatment of ankylosis of the hip or the shoulder joints than of such joints as the knee, the wrist, or the ankle, which are less covered by layers of the soft tissues."

Only those drugs can be used for ionization which are soluble in water and are dissociated when dissolved, and these are known as "electrolytes" (§ 16). They include inorganic neutral, acid and basic salts, and the similar organic compounds, such as salts of the alkaloids, salts of organic acids, as for instance salicylic, but not such things as chloroform or iodoform, nor carbolic acid, which is an alcohol, and not an acid.

Hydrogen, the metals and the alkaloids are introduced from the positive pole; their ions are positively charged, and are repelled from the positive pole towards the negative. Acids and hydroxyl are introduced from the negative pole.

The depth to which ions penetrate in a given time varies for different ions, as they have different "velocities." The simpler ions, such as hydrogen, hydroxyl, lithium, have high velocities, and penetrate more rapidly. The heavy or complex ions move slowly, but, on the other hand, a greater weight of a heavy ion will enter for a given current. In any case it is probable that the penetration is not to a great depth, for the ions, which carry all the current at the parts nearest to the electrodes, pass on their charges to the tissue ions after penetrating more or less, and so lose their impetus. Experiments made with radium ions show that the penetration is sufficient to produce definite effects

Haret and Danne found in a rabbit that after an application of thirty minutes to the foot, the radium had penetrated through the skin and all the soft tissues, and some was found in the bone.

In a heifer another experiment lasted thirty minutes, and the current was 20 milliampères. The animal was killed twenty-four hours later, and again the radium was found to have reached through the whole thickness of the part treated, including the bone. The experiment was made on the fore-limb, which measured 7 centimetres in thickness.

There is a difficulty in introducing the ions of the heavy metals to any depth because they enter into combination with the phosphates of the tissues to form insoluble precipitates, and so go out of action. Zinc phosphate, being rather less insoluble than the others, may penetrate a little deeper. Silver, which readily forms an insoluble chloride, is not suitable for ionic introduction except for the very superficial layers. Mercury also precipitates very readily in contact with the juices of the body.

The heavy metals being specially valuable as germicides, they

can be used with success for superficial infections, if not for deeper ones.

To estimate the quantity of an ion which will be introduced into the body in a given time by a given current we have to consider two factors, the electro-chemical equivalent and the ionic velocity, for it has been found that different ions possess very different velocities; for instance, the velocity of the hydrogen ion is five times as great as that of chlorine. Potassium and chlorine have very nearly identical velocities, and we may calculate the quantity of each of these ions introduced at electrodes moistened with a solution of potassium chloride. The electro-chemical equivalent (§ 20) of potassium, or the weight set in movement by 1 coulomb, is about 0·4 milligramme, which, multiplied by six, gives the weight of 2·4 milligrammes as the quantity moved by ten milliampères in ten minutes. The corresponding figure for chlorine is about 2·2 milligrammes; and, the velocities being taken as equal, the figure for their "shares of transport" or "transference numbers,' viz., the amount which enters the skin, is obtained from them as follows: One-half of 2·2 milligrammes for the chlorine, and one-half of 2·4 milligrammes for the potassium. That is to say, the amount of the chlorine introduced is half of the figure obtained from the electro-chemical equivalent multiplied by the current and the time, and that of the potassium is half of its corresponding figure.*

When electricity is to be used for the sake of its ionic effects, the continuous current must be used. The applications generally require strong currents—up to 50, 60, or even 100 milliampères with large areas, with durations of fifteen or twenty minutes, and occasionally for half an hour or an hour. Such currents would undoubtedly blister and damage the skin if full precautions were not taken to prevent this. Care must be taken to avoid all irregularities, jerks, or accidental interruptions of

* The formula is as follows: $\frac{a}{a+k}$ for the anion, $\frac{k}{a+k}$ for the kation, where a is the velocity of the anion, k that of the kation. To obtain the amount of the ion which enters the body, the product of current, time, and the electro-chemical equivalent, which gives the amount set in movement, must be multiplied by $\frac{a}{a+k}$ for the anion, and by $\frac{k}{a+k}$ for the kation. For a table of electro-chemical equivalents and of ionic velocities, see Appendix.

current during the application, and for this reason an apparatus like that shown in Fig. 81 is better for ionic medication than a portable battery. The attachments of the conducting cords must be secure; rubber-covered cords should be used to avoid corrosion, which is very apt to take place with silk-covered cords, through the accidental moistening of the cords by the solutions at the ends near their junction with the electrodes.

The electrodes should have two layers of felt sewn on to them, and between the felt and the skin there must be cotton cloths, folded in sixteen layers and well soaked with the appropriate solutions. These thicknesses of tissue are to delay the arrival at the skin surface of the caustic ions H and OH, which originate at the metal surfaces (§ 162). These coverings and cloths must be larger than the metal part of the electrodes, and must cover a good large area when large currents are used. They may be made secure by bandages, which also ensure a good contact between the cloth and the skin. The skin should be washed before the application, to remove any greasy matter, and the soap used must also be rinsed away with care. If any abrasion or acne spot exists on the skin at the place where the pads are to be applied, it must be carefully covered with a small piece of rubber plaster. The current must be turned on quite gradually, or large magnitudes of current will not be reached without pain or burning. During the commencement of the application the patient must be told to mention any development of spots of sharp, pricking pain, as these may mean that the skin is not taking the current evenly, and that a blister is likely to form. An even burning sensation felt all over the covered area, like that of a mustard-leaf, is a sign that the current is entering evenly. If the milliampère-metre, after being steady, should begin to go up quickly during the application, it may mean that the skin is giving out.

The ionic applications should be repeated every other day, if the skin will bear it, but not oftener. In general one may say that one long application is better than two brief ones.

185. **"The Refreshing Action" of the Galvanic Current.**—A peculiar effect of direct currents, which may be due to the transport of ions, was investigated by Dr. Vivian Poore,* who made some remarkable experiments upon the refreshing action of the continuous current on the fatigue of muscles, produced when a weight is held out steadily at arm's length. In one

* "Electricity in Medicine and Surgery," Dr. G. V. Poore, London, 1870.

instance a patient, after holding out his arm horizontally for a period of four minutes, with a weight of seventeen ounces in the palm, felt great pain and fatigue in the muscles, and declared his inability to go on, but was relieved at once by the passage of a constant current in a descending direction along the arm. Another person, experimented on in the same way, felt pain and fatigue after holding out the weight at arm's length for seventy seconds, but the application of the current at once removed both and he continued to support the weight for five minutes and a quarter, and at the end of that time was still able and willing to go on. Dr. Poore tried similar experiments on several of his friends, and they all tend to show that the endurance of voluntary muscular action is very greatly increased by the passage of a constant current, which also mitigates or abolishes the fatigue felt during or after the effort.

Dr. Poore also demonstrated that the force as well as the endurance of a muscular effort could be increased by a galvanic current. Eight successive squeezes with a dynamometer, at intervals of ten seconds, gave an average of 48½ pounds for each squeeze, but eight more squeezes, with the aid of the current, gave an average of 59½ pounds, although they came ten minutes after the first series, and while there was distinct consciousness of fatigue from the first experiment.

The current used was never strong enough to produce involuntary contraction of the muscles.

Capriati has more recently examined this matter with the aid of scientific methods of measurement. He has found that the direct current applied along the spine increases the muscular force of an individual, and that such increase persists for one or more days afterwards. Similar results followed applications of direct current to the limb tested, but were less marked; and finally they may also be observed after electrification by static charging. The direction of the current, or the polarity of the charging, appear to have had little or no importance. The magnitude of current used in the first experiments on the spine was 10 to 15 milliampères.

186. **Inhibition of Strychnine-Poisoning by Currents.**—Another peculiar effect of the current upon the symptoms of strychnine-poisoning has been described by Charpentier and Guilloz.* They

* *Archives d'Électricité Médicale*, 1904, p. 69.

have stated that the passage of a direct current arrests the manifestations of poisoning by the alkaloid in frogs and in guinea-pigs. So long as the current flows there is quiescence, although the stoppage of the current is quickly followed by the development of the characteristic tetanic spasms. By means of prolonged electrical applications death from strychnine may be prevented as the animal is kept quiet until the poison can be eliminated by the kidneys.

187. **Electrolytic Effects.**—The electrolytic action of the current is used in surgery as a means for producing destruction of tissue in a simple and minutely localized manner. This is effected by the agency of the chemical products set free at the poles during the passage of the current. As these bodies are different at the two poles, so the actions which take place at the poles differ from one another to a certain extent. The advantages of being able to localize the effects so precisely is well seen in the operation for the removal of hairs, for here the destructive effects are confined to such a minute area in the immediate neighbourhood of the hair follicle that no perceptible scar is produced, although the hair follicle is eradicated. Electrolysis has been used for the following purposes: (1) The removal of superfluous hair, of moles, and of warts; (2) destruction of nævi; (3) coagulation of blood in aneurysms; (4) destruction of strictures of the urethra, lachrymal canals, œsophagus, rectum, and Eustachian tube. Electrolysis has also been used for the destruction of cancerous growths and for the treatment of fibromyoma of the uterus.

Needles are used commonly in surgical electrolysis. They may be of platinum, in which case the destructive effects are due to chlorine at the anode, or to sodium hydrate at the kathode. Steel needles may be used at the kathode to take the place of platinum, but they must never be used at the anode, for the effect there is to form an insoluble black oxide of iron, which remains as a permanent black mark in the skin. Indeed, if tattooing were to be done, it could be accomplished much more rapidly and safely with a steel anode than by the methods of puncture and rubbing in Indian-ink. Needles of zinc are very useful in some electrolytic procedures, used as anodes. Here the destructive effect is due to the ions of zinc sent off from the needle, and the zinc chloride formed at its surface. Zinc electrolysis is valuable for small nævi, for small moles, and for warts.

In the latter it seems to have a specific effect. For the removal of hairs a fine platinum wire (negative) is used.

188. **Effects of Static Applications.**—The effect of a static charging is to increase the frequency of the pulse and to raise the blood-pressure. This was observed as long ago as 1748, when Jallabert noticed in a certain case an acceleration of the pulse from 80 to 94, and saw a phlebotomy wound which had ceased to bleed recommence after a few minutes of Franklinization, and give a stronger jet than before.

The effect on the nervous system is sedative, patients sleep better, and they may even show a tendency to fall asleep during the process of treatment.

Capriati, experimenting upon tadpoles with static charging, found that they developed more energetically and rapidly than the control individuals. And Picciano, who watched the development of silkworms under different forms of electricity, found that the product of those subjected to Franklinization was superior to that of silkworms which had developed under ordinary conditions.

D'Arsonval found a slight increase of the respiratory exchanges under the influence of static treatment. Other writers have stated that the thermogenesis of the human body increases sensibly during, and for some time after, each Franklinization.

In practical treatment it is noticed that some patients, particularly such as are weak and anæmic, experience a marked feeling of improvement as soon as the charging begins; while others, especially gouty and plethoric individuals, remain indifferent, or may even show by their words or movements that they find it uncomfortable. It is probable that this is due to the rise of blood-pressure, which is the chief physiological phenomenon produced by statical applications. The blood-pressure should be made the guide in determining whether static treatment should be given or not. Those whose pressure is low feel better as soon as it is raised, and derive permanent benefit, while those whose blood-pressure is already high are made uncomfortable by the treatment. Bonnefoy has also noted that high arterial tension is a contra-indication to statical treatment.

Many writers report favourably on the value of static treatment in neurasthenia, and in the treatment of insomnia and mental fatigue; and in certain forms of insanity and morbid mental states favourable results have followed statical applications.

In the nervous disturbances which occur about the time of the menopause decided benefit may be obtained from simple static charging with the use of the negative breeze.

Statical applications undoubtedly act upon the function of menstruation, and I have several times found that statical treatment restored regularity in cases of amenorrhœa. Golding Bird has also insisted upon the value of this effect of statical treatment.* With patients receiving a course of treatment for conditions quite unconnected with the generative functions it is common to remark some effect upon the menstrual periods. Professor Doumer,† of Lille, has published his notes on 400 women treated by static electricity. In 342 the uterine functions were quite normal; in the rest, 58 in number, there was some complaint of menstrual trouble, mainly of the nature of dysmenorrhœa. Among these patients there was a hastening of the commencement of the period in 68 per cent., and an increase of the flow in 77 per cent. Among the 400 cases there were 178 who had some pains or discomfort about the date of the commencement of their periods, and 73 per cent. of these, 130 persons, were relieved of these symptoms, while the remainder were not. Menstrual irregularity was present in 51 cases, and quickly disappeared in 31. These results followed for the most part upon simple electrostatic charging, but the breeze or the roller applied to the lumbar region produced a more prompt result.

When the brush discharge is used, rise of blood-pressure probably depends upon the peculiar stimulation of the sensory nerves of the skin which is produced. The spark and brush discharge of high frequency is said to have a similar action on blood-pressure. With the point electrodes these sensory impressions can be made to vary from a cool and gentle breeze effect to an intensely pungent pricking, and much of the success of static applications depends upon the adjustment of the degree of cutaneous stimulation to the nature of the individual case.

The effect of brush discharges upon pain in the superficial cutaneous nerves, as, for example, in headache or neuralgia, is sometimes very striking. Care must be taken when treating patients for the relief of pain not to spoil the effect by accidental

* Golding Bird, "Electricity and Magnetism," 1849, Lecture V. and Appendix B.

† *Archives d'Électricité Médicale*, 1897, p. 96.

sparks or shocks. With the negative point (the patient charged positively) there is not so much risk of this, for sparking does not occur under these conditions, except with the point at very close quarters.

The effect upon the skin of a strong brush discharge through woollen clothing remains plainly visible for some hours afterwards, in a persistent reddening or in the form of urticarial elevations.

The most intense cutaneous stimulation is that produced by the roller electrode (§ 127). The shock and muscular contraction which is produced by the application of a spark from the knob or ball electrode relieves pains of a myalgic nature, and often relieves them instantaneously. Probably it acts by a sort of forcible wrenching of muscle fibres. It is useful to request a patient with a pain in a muscle to assume the attitude which provokes or increases the muscular pain, and then to apply the spark or sparks to the painful part. In lumbago this treatment by sparks sometimes relieves promptly.

The local action of static discharges upon the skin is shown by its effects in certain skin diseases. As is the case with high-frequency currents, the brush and spark discharges produce ozone and nitric vapours which may have an effect in bringing about the result. In pruritus, which is so often intractable to many forms of treatment in psoriasis, in eczema, and in varicose ulcers of the leg, the brush discharge is often efficacious. Albert Weil has reported a case of lupus cured by the brush discharge and static sparks.* No doubt the local hyperæmia which the applications produce plays a large part in bringing about the results. It has been frequently noticed by others, and it has also come under my own observation, that repeated applications of the brush discharge to the scalp seem to stimulate the growth of the hair. Damoglou† has reported a series of cases in which this effect has been well marked. In one case—that of a girl of nineteen under treatment for neurasthenia by static methods—the hair, which at the commencement only reached to the shoulders, had after two months grown so as to reach down to her knees.

189. **Effects of High-Frequency Currents.**—We have already seen (§ 132) that these currents have the peculiarity of producing

* *Progrès Médicale*, 1900.

† *Annales d'Électrobiologie*, April, 1911.

no muscular shock nor any painful sensory effect, even when applied as currents of very large quantity.

High-frequency currents may be given as a general application by means of ordinary electrodes grasped in the hands or attached to some part of the body surface, or they may be used by what may be known as "sparking methods," in the form of sparks, effleuves, or brush discharges, as, for instance, with the glass vacuum electrodes shown in Fig. 131. The effects in the two cases are different.

In the former the parts of the body near the electrode are traversed by currents of large magnitude, and these exercise the thermal action referred to in § 177, and set up a local vascular dilatation, which in its turn reacts upon the general circulation, and upon the heart's action, if the local effect is of sufficient extent and magnitude. Thus are produced the various effects which have been observed to follow general applications of high frequency. The favourite method is to use the condenser couch (§ 133), with the patient holding the handles, both of which are connected to the same pole of the apparatus. The condenser couch is a "monopolar" method, and is more free from any disturbances which might arise through irregular working of the spark-gap, whereas if both poles are applied to the patient there may at times be a disagreeable tetanizing effect, which should be avoided. The method of auto-conduction (see p. 210) is not much used.

Among the physiological facts observed by D'Arsonval from general applications of high-frequency are an increase of the output of CO_2, noted as having been raised from 17 to 37 litres per hour; an increase of heat production, from 79 to 127 calories per hour; and an increase of nitrogen and phosphoric acid in the urine.

The effect on the general blood-pressure has been much considered. Some writers have reported permanent lowering of the blood-pressure in cases of arterial hypertension, particularly by the method of auto-conduction, but others have been unable to observe this. In the experiments of Bergonié, Broca, and Ferrié,* which were designed to settle the question of the influence of high-frequency currents upon arterial tension, very powerful apparatus was used, and a number of patients were treated by auto-conduction, some of them being cases with

* *Archives d'Électricité Médicale*, 1907, p. 731.

definite arterio-sclerosis. Of thirty-five patients, twenty-one showed no change in blood-pressure as the result of the treatment, ten gave a rise of blood-pressure, and four a reduction.

Sloan,* who investigated the effects of high-frequency currents, and particularly those of the condenser couch method, came to the conclusion that the first effect was upon the peripheral circulation, and that this was usually a vaso-dilator effect. Following this came a response on the part of the heart, which corrected the tendency to a fall of blood-pressure, and quickly raised it to its former level, or to a slightly higher level.

If the heart was weak or the bloodvessels rigid, this compensation action was imperfect, and there might be a fall of pressure, even of considerable amount, so that a tendency to syncope was noted in some cases. On this account it is desirable to watch the pulse when a patient, whose heart may not be sound, is submitted to high-frequency treatment for the first time.

The local warming action of the currents, and the vaso-dilatation which follows it, have a tendency to relieve congested organs, and high-frequency currents have accordingly been found useful in the treatment of piles and of enlarged prostate when the piles or the enlargement of the prostate are mainly a matter of congestion; but when fibrous and other structural changes are far advanced, the high-frequency treatment will naturally be insufficient to effect a cure. For these conditions a direct application of the current to the affected part is necessary, and bare metal electrodes of suitable shape are used.

Neuritis, neuralgia, joint affections, gout, insomnia, and a host of other affections have been treated by high-frequency currents, and good results have been recorded in many instances. But in general the practitioner should continually keep before his mind the general proposition that, apart from the sparking methods, high-frequency currents produce local warming, and vaso-dilatation, and that at present this is the only sure ground upon which to base his high-frequency treatments. The effects of this physiological action are doubtless of a far-reaching kind, and may lead to many secondary results of value. It follows, too, that large currents, say of 500 milliampères or more, must be used if adequate results are to be gained.

The use of high-frequency discharges for what may be called "spark effects" are made with the glass vacuum electrodes

* *Lancet*, 1907.

(Fig. 131), or by means of the effluve from metallic points held just beyond sparking distance. Actual sparks are also used, especially for the destruction of moles, warts, etc. The Oudin resonator is often used for this class of high-frequency treatment (§ 134). The action of the effluve or of the multiple fine sparking of the vacuum electrodes seems to be one of stimulation or counter-irritation, and perhaps the generation of heat and the production of ozone and of oxides of nitrogen at the actual skin surface may play a not unimportant part in bringing about a favourable result.

It has been shown by A. G. Foulerton and A. M. Kellas* that high-frequency currents appear to have no direct bactericidal action, but that there is a production of ozone and of nitrous and nitric acids by the brush discharges of high-frequency apparatus, and that these exercise a strong germicidal effect upon cultures of bacteria. They express the opinion that when an ulcerated surface is treated by the brush discharge of a high-frequency apparatus the method may be regarded mainly as a means of bringing germicidal substances in an active condition into contact with the bacteria present in the lesion. Possibly the results reported to have followed high-frequency treatment in gonorrhœa and in pyorrhœa are brought about in this way.

The morbid conditions of the skin in which success has been most commonly obtained with high-frequency treatment are pruritus, psoriasis, eczema, acne, sycosis, and lupus.

The spark from a metallic electrode is of value in angioma and in tubercular lupus. For flat angiomata (port-wine mark) Bergonié applies an aigrette of very numerous small sparks; the tissue becomes pale after a few seconds of this application. This is followed by an inflammatory reaction, which results in a cure of the subcutaneous condition, with more or less decolorization of the epidermis. Strebel of Munich finds that active sparks may cure lupus and rodent ulcer. His application is by a pointed metallic electrode from the Oudin resonator, held at a distance of 1 or 2 millimetres from the surface; a stream of sparks is allowed to pass uninterruptedly. After about five seconds the skin blanches, the epidermis is shrivelled or fissured, and the blood-vessels are all constricted. The spark is allowed to act for ten or twenty seconds. An inflammatory reaction is produced, and this is succeeded by elimination of the morbid tissues and a

* *Lancet*, April 25, 1903; May 19, 1906.

slightly depressed cicatrix, at first red, but which soon becomes indistinguishable from the sound skin. Small moles and warts may be destroyed in a similar way. When applied very vigorously in this way the process is called Fulguration.

When the diathermy apparatus is used, the high-frequency effects are modified by reason of the larger currents, but otherwise they are similar in kind. Diathermy is used as a bipolar method with both electrodes applied to the patient, and usually the electrodes are so attached as to submit a part of the body, such as a joint or a limb, to the very definite heating effects produced by the large currents. It has been tried in various joint affections, especially in gonorrhœal arthritis, and in this it has seemed to be a very valuable mode of treatment. Some good results have also been obtained in other forms of arthritis, though not in advanced cases of osteo-arthritis.

Diathermy is also used for producing heat coagulation in the destruction of morbid growths such as nævus, in malignant disease in the mouth and throat, and in other conditions where local destruction is desired. It has the merit of opening no bloodvessels or lymph channels, and therefore of avoiding re-infection of the wound during the operation. A small electrode is used for these surgical applications, the second electrode being large, to avoid destructive heating except at the desired point. Brief applications of a few seconds are sufficient for small areas.

190. **Effects of X-Ray Applications.**—Exposures to X rays, if too long or too frequently repeated, set up a dermatitis of a very peculiar kind. Oudin* has given a graphic account of the changes which occur in the most severe form of X-ray dermatitis.

At the end of one or two days (or even as late as two or three weeks) from the time of exposure a slight erythema shows itself, and this, instead of disappearing, gradually becomes of a red or livid colour, something like that of a chilblain, until at the end of a lapse of time which may be ten or twenty days, or even longer, the erythematous patch becomes the seat of troublesome irritation, which becomes worse and worse. Small vesicles or pustules develop on its surface, and these break and leave small ulcerations. Pigmentation of the surrounding skin develops during the same period, and the hairs may fall out.

Ulceration gradually involves the central part of the affected

* "Accidents dus aux rayons X," *Archives d'Électricité Médicale*, September, 1902.

area, and finally a yellowish adherent leathery scab or crust forms, and remains unchanged for many weeks, the part being intensely painful. After the lapse of a longer or shorter time the necrotic patch separates, leaving a raw red surface which heals only very slowly, and may break down again from slight causes. Nothing in the way of dressings seems able to relieve the pain or to accelerate the healing process. It seems to be useful to apply some impermeable dressing, because the contact of air with the sore is quite painful. A year may elapse before the part heals.

The gradual onset after a latent period suggests that the lesion is a tropho-neurotic one, due to the damage sustained by the superficial nerves of the part. Certainly there is partial anæsthesia in and around the affected area, which may persist for many months. After healing, the part may gradually acquire a nævoid character, and remain irritable and tender for many years.

X-ray burns are specially produced by the rays emitted by "soft" tubes with a resistance of less than 3 inches of spark-gap.

Fortunately, X-ray dermatitis does not always follow this tragic course. In the earlier stages the symptoms may recede without the formation of a necrosed area, and this is most likely to follow if great care be taken to protect the part from every chance of accidental injury. So soon as the advent of a severe burn is apprehended, the part should be covered with cotton-wool and a bandage. No antiseptic lotions or ointments, no bathing with water nor poulticing, should be employed. The writer, by proceeding in this way, was fortunately able to arrest the progress of a serious burn on the dorsum of his own hand. The part was kept covered with a layer of wool, and protected by a glove for three weeks. At the end of that time the livid œdematous condition had passed off, and the skin separated in one large piece, leaving a tender but healed surface beneath. Twelve years have now elapsed since the time of the burn, which was produced as an experiment, and the area is covered with nævoid patches (telangiectases), which are gradually diminishing. The epidermis is thin and smooth, and easily affected by cold, and is devoid of hair.

The effects of a series of X-ray exposures of moderate duration are not the same as those produced by one or two prolonged exposures. Most X-ray burns of the severe kind just described

have followed one or at least few exposures of inordinate length. In X-ray treatment it may be necessary to push the exposures to the very verge of causing dermatitis. In fact, dermatitis is often intentionally caused, and in experienced hands a sharp dermatitis can be set up without the disastrous sequels described by Oudin. At the same time, no one must fancy that there is any immunity from severe burns in such cases. Many severe burns have been produced during a course of treatment, but generally there is sufficient warning in the shape of harmless erythema to warn an experienced operator. Some peculiar instances of dermatitis coming on after a long interval have been described by Oudin.* In these, after six months' interval, some slight cause seems to have provoked ulceration of a rebellious type, very much like acute X-ray dermatitis. Bergonié and Spéder† have reported a number of peculiar symptoms following soon after X-ray applications. Among them they mention erythema and swelling in neighbouring but shielded areas.

The amount of X rays which can be administered with safety in one application can now be determined by Sabouraud's pastilles (§ 146), and single maximal doses are now often given.

Scholz‡ and also other observers have recorded a falling of hair or a production of dermatitis not only at the point where the X rays entered, but also at their point of exit, the intervening tissues remaining unaffected, and this seems to show that destructive effects first manifest themselves upon the epithelial cells, although as soon as the injury has reached a certain intensity, an inflammatory action appears which manifests itself in a marked dilatation of the vessels, with gathering leucocytes and emigration of the blood-corpuscles.

The changes in the vessels are of importance as affecting the further development and healing of the ulceration.

A different form of dermatitis is seen in X-ray operators, in persons who are much engaged with X-ray apparatus or in the manufacture of X-ray tubes. In these persons the skin of the backs of the hands gradually becomes chronically inflamed and thickened, and cracks develop round the knuckles; the hairs fall

* "Accidents tardifs dus aux rayons X," *Annales d'Électrobiologie*, 1901.

† "Sur quelques formes de réaction précoce après des irradiations Roentgen," *Archives d'Électricité Médicale*, March 25, 1911.

‡ *Archives f. Derm. und Syphilographie*, 1902.

out, and are not renewed; the nails become brittle, longitudinally striated and deformed, and the parts are irritable or intensely painful. Eventually ulceration sets in, and when this stage is reached treatment becomes almost ineffectual. A good photograph of this condition can be seen in the *Archives of the Roentgen Ray*, 1904, vol. viii.; and a graphic account of his own suffering from chronic dermatitis has been written by Mr. J. Hall-Edwards,* with photographs of the state of the hands in a severe case. See also St. Bartholomew's Hospital Reports, vol. xlv., 1909, for a report with illustrations of seven cases of simple X-ray dermatitis, and notes of twenty-four cases of malignant disease following it. Complete removal of the sufferer from all exposure to X rays for a period of many months affords little relief.

Amputation of the fingers or the upper limbs has been necessary in a number of cases, and death from development of carcinoma in the chronically inflamed tissues has ensued in numerous instances.

Conjunctivitis and retinitis have been known to follow X-ray exposures under the conditions causing chronic dermatitis in X-ray operators. X rays have a destructive influence upon leucocytes, and repeated exposures cause a decrease in the number circulating in the blood, which has been turned to account in the treatment of leukæmia. At the German Congress of Internal Medicine, Drs. Linzer and Helber,† of Tübingen, stated that in small animals the blood could be almost denuded of leucocytes by repeated applications of the rays, and added that the destruction of the leucocytes could be observed under the microscope in fresh preparations. They considered that the destruction of the leucocytes set free toxic substances in the serum, and attributed the nephritis observed in irradiated animals to toxins formed by the destruction of the leucocytes. It has been stated that under the action of the rays lecithin is broken up, with the setting free of choline and methylamine, and the toxic symptoms sometimes observed in patients who have received large doses of X rays might be explained by the results of this change. All young and growing tissues are especially vulnerable, and the glandular tissues also seem very susceptible to the effects of X rays.

* "On Chronic X-Ray Dermatitis," *British Medical Journal*, October 15, 1904.

† Reported in *Lancet*, May 13, 1905.

X rays have been shown by Albers-Schoenberg and others to exercise a peculiar destructive action upon the development of spermatozoa, so that male animals exposed to the rays become sterile, though their potency remains unimpaired. Bergonié and Tribondeau* have written an important paper on the histological changes found in the testes of rats after X-ray radiation. Dr. Tilden Brown has reported on the results of the examination of the seminal fluid of seven workers with X rays, and found spermatozoa absent in four of them, who had been exposed for the longest periods of time to the influence of the rays. The condition is probably one which may be recovered from. A case has been reported by Cleaves in which both the disappearance and the subsequent reappearance of the spermatozoa was observed. In the female rabbit a similar destructive action upon the ova in the ovary has been observed to occur by Halberstaedter. X rays suitably administered are capable of causing amenorrhœa in women, by their effect on the ovaries, and this is made use of for the treatment of uterine fibroma by the production of an artificial menopause. The action of X rays upon the development of hens' and of silkworms' eggs has also been examined and reported on. The effect of the rays seems to have been uniformly destructive.

X rays are used in medical work in the treatment of many skin diseases, in lupus, rodent ulcer, and in malignant diseases. In the latter the results obtained are occasionally valuable, though as a rule the relief is only temporary. In 1905 Bergonié† summed up his experience in mammary cancer as follows: "In cancer of the breast, operable, with rapid invasion, in a young woman before the menopause radiotherapy cannot at present show any established successes, complete or lasting, for more than a few months. In non-operable cases in young people radiotherapy is a palliative treatment, diminishing or suppressing pain, closing superficial ulcerations, removing the fetor of the ichorous discharge, or even drying it up. But it does not prevent general involvement sooner or later. In cases recurring after operation, the conclusion is the same if the woman is young; the results are perfect at first: the cicatrix becomes flexible, the epithelial nodules flatten out and disappear, the

* *Archives d'Électricité Médicale*, 1906.

† "Sur l'État actuel de la Radiothérapie," *Archives d'Électricité Médicale*, August 12, 1905.

glands can no longer be felt; but later on generalization takes place; cough announces the mediastinal invasion, and one can only delay, not prevent, a fatal termination. In scirrhous cancer in older women, and in slow-growing forms of cancer of the breast, the results are much better. The X rays will keep the patient for a long time free from pain, from ulceration, and from any considerable advance of the disease, and the treatment seems to be advantageous in every way." The opinion to-day remains much the same. In internal cancer the results are very seldom of any value. There may be some temporary relief of symptoms, but nothing more can be expected in the present state of our knowledge.

In sarcoma a certain small number of cases appear to have been benefited permanently, and a much larger number have shown striking but temporary improvement.

In tubercular affections of the lymphatic glands a certain degree of success has been obtained. In leukæmia great amelioration of symptoms may be produced—at least, for a time; but it is not yet possible to claim real permanent successes in this disease. In the treatment of adenoids, of enlarged tonsils, and of exophthalmic goitre, the power of X rays to arrest the growth of glandular tissues has been used with advantage.

In tinea tonsurans X rays afford a remedy of great value, and by their use the duration of the disease can be greatly reduced. The action is an indirect one, for the rays cause a temporary loss of hair in the parts exposed, and before the hair grows again the fungus has disappeared from that area. The rays have no direct action upon the ringworm fungus.

191. **The Action of Radium Rays.**—The rays of radium affect micro-organisms in varying degree. Non-spore-bearing bacteria are generally killed after two to fourteen hours' exposure. Spores may not be killed with less than seventy-two hours' exposure. As the distance between the radium and the micro-organism is increased, the germicidal action becomes less marked, so that after thirty hours' exposure at one centimetre some may survive, and at ten centimetres there is little or no action.

Radium rays exert a marked retarding influence on the eggs of sea-urchins. Spermatozoa are rapidly enfeebled and killed, and ova exposed to radium rays may develop irregular embryos by parthenogenesis.

The larvæ of insects kept in a tube with radium for twenty-

four hours died in two or three days; in them, too, the nervous system was most affected.

Danysz* found that the action of radium on the skin is not immediate, but on the eighth, fifteenth, or even twentieth day there is some congestion. A sample containing about 50 per cent. of pure radium bromide produces an appreciable congestion of the skin after an exposure of a few minutes. If placed in contact with the skin of a guinea-pig for twenty-four hours, it causes complete destruction of the epidermis and dermis. The deeper connective and muscular tissues are little affected. If the radium be placed under the skin, a relatively feeble effect is produced on the connective tissues and muscles. The epidermic tissues seem to absorb the rays that produce the pathological effects. A tube of radium placed in the peritoneal cavity produced no lesions comparable to those produced on the skin, and the intestines and serous membranes seemed to be very slightly sensible to these radiations.

The nervous system is especially sensitive. A tube of radium placed under the skin over the vertebral column and part of the cranium of a young mouse, one month old, caused at the end of three hours paresis and ataxia; after seven to eight hours, tetaniform convulsions; and death in twelve to eighteen hours. Mice, three to four months old, died with the same symptoms in three to four days, and those one year old in six to ten days. Guinea-pigs, eight to twelve days old, similarly treated for twenty-four to forty-eight hours, but with the tube applied to the lumbar region, suffered in one to three days from complete paralysis of the hind-quarters and tetaniform convulsions. Death ensued in six to eight days. An adult rabbit in which a tube was placed under the dura mater for eight hours showed nothing abnormal for two days, but on the third it had hemiplegia. Horsley and Finzi† found that a tube of radium applied to the brain in monkeys produced changes in the blood-vessels, but not primarily in the nerve tissues, though these naturally suffer in consequence.

When radium is placed near the eye, a sensation of light is perceived.

* *Acad. des Sciences*, February 16, 1903. See also *British Medical Journal*, February 13, 1904.

† "The Action of Filtered Radium Rays when applied directly to the Brain," *British Medical Journal*, October 14, 1911.

Radium rays give rise to burns of the skin like those caused by X rays, and the scars of these burns are often deeply pigmented, and may develop telangiectases like those which follow X-ray dermatitis.

Radium has been applied to the treatment of the conditions for which X rays have been found useful. It is useful in nævus,* and in port-wine mark, but acts better on the young growing tissue of the former than on the latter.

Many cases of rodent ulcer have been treated successfully by radium bromide. In the *British Medical Journal* for January 23, 1904, Mackenzie Davidson published five cases treated with radium. The quantity used by him in these cases was five milligrammes. It was enclosed in a glass tube, and affixed with plaster to the affected part. Exposures of twenty or thirty minutes were given, and in some cases longer. A reaction is produced on or about the eighth day, and is complete after the lapse of another fourteen days. Nowadays rodent ulcer is treated by longer and stronger applications. In rodent ulcer radium finds its best field for treatment. The radium rays are often filtered by enclosing the radium in a metal sheath, so as to prevent the escape of the alpha and beta rays. In the attempt to cure malignant disease radium has been very much used, and a vast quantity of literature dealing with the subject has been published. Those who wish to pursue the subject should do so in the writings of Dominici,† Wickham and Degrais,‡ and numerous other authors. Briefly, it may be said that the prospects of cure by radium in any particular case are very slight. Here and there favourable results of a more or less lasting kind seem to have been secured, but of all the numbers of cancer cases which have been treated by radium in Paris or elsewhere, it is probable that the survivors are so few as to be almost non-existent.

The use of radium emanations for the treatment of gout and rheumatism has lately come into notice. The good effects of the treatment of these conditions by mineral springs has been attributed to the presence of radium emanation in the waters, and as the radium emanation is a gas, it has been supposed that

* Lewis Jones, "On the Treatment of Nævus by Radium," *British Medical Journal*, August 21, 1909.

† *Archives Generales de Médecine*, July, 1909.

‡ "Radium Therapy." Translated by S. E. Dore. London, Cassell and Co.

its best mode of application is by inhalation. Apparatus has been devised to permit patients to breathe an atmosphere continuously impregnated with radium emanation, or to drink waters charged with it. It is said that uric acid tophi artificially produced in rabbits have been made to disappear by submitting the animals to the action of radium emanation, either inhaled or swallowed.

His* has particularly advocated this form of treatment. Papers by Saubermann,† Armstrong,‡ and Engelmann § may also be consulted.

Radium has also been introduced into the tissues by ionization, and a good result has been reported in a case of sarcoma, and in nævus of the lip.‖

192. **Effects of Light Rays.**—H. Strebel¶ has shown that light may act as a therapeutic agent either by the light rays, by the associated heat rays, or by both together. The application of light containing heat rays from a number of incandescent lamps to the surface of the body increases metabolism, stimulates the formation of hæmoglobin and pigment, and produces general or local capillary hyperæmia. Such rays are an ideal sudorific, producing profuse perspiration without embarrassing the heart or respiration or causing other discomfort, and were first made use of for this purpose by Kellogg (§ 97).

Strebel states that some rheumatic patients are cured after using the light-chamber five or six times, others are improved, but others, again, are not benefited. The same has been observed in gout. Any improvement is probably due to the sweating produced, rather than to any specific action of the light rays. No marked improvement in the movements of stiff joints is observed. In nephritis the electric light bath is a safe and pleasant sudorific. In heart disease the effect varies according to whether the arc or the incandescent lamp is used as the source of light. With the incandescent light bath, the pulse-rate is increased. The application of the arc-light, of which light rather than heat is the chief constituent, causes the pulse-rate to fall at first, possibly owing

* "The Treatment of Gout and Rheumatism by Radium," *British Medical Journal*, February 4, 1911.

† *British Medical Journal*, October 14, 1911.

‡ *Ibid.* § *Lancet*, August 12, 1911.

‖ *British Medical Journal*, Epitome, 1911, No. 105.

¶ *Deutsche med. Wochenschrift*, 1900.

to reflex vagus stimulation. In the arc-light bath the diminished frequency of the pulse continues until the temperature of the chamber is sufficient to produce free diaphoresis; the rate then increases, but without attaining the frequency observed in the incandescent light chamber. The determination of blood to the skin relieves the congested internal organs, while the sweating tends to diminish the anasarca, and so to relieve cardiac embarrassment. In obesity some loss of weight may follow. In anæmia the light of the arc has been found to increase the red blood-corpuscles and the percentage of hæmoglobin. The amenorrhœa of anæmia may be overcome by its use.

Strebel finds that by the light-bath, and by local application of concentrated light to the chest, coryza may be relieved, and chronic bronchitis with emphysema is often greatly improved. Light without radiant heat has no effect in these cases.

On cutaneous diseases, and especially those of bacterial origin, the light rays and the chemical rays, as opposed to heat rays, are alone efficacious. In some cases of syphilis general light-baths, combined with local application of concentrated light, deprived as far as possible from radiant heat, appeared to give good results. The utility of the treatment by pure light rays is most evident in wounds and ulcers. Soft chancres heal, and even varicose ulcers of the leg may be cured in one to five weeks. Light is an excellent application to boils and acne. If the furunculosis is general, light-baths must be used as well as local irradiation.

A lamp of high candle-power—as, for instance, a carbon filament lamp of 500 candles—is used as a therapeutic application for the relief of muscular pain, lumbago and sciatica, and for the treatment of skin diesases. The lamp is suspended from a support, and provided with a polished reflector, and the part to be treated is placed beneath the lamp, which is kept in a swinging movement, so as not to cause excessive burning at any one spot. It has been called the "leucodescent lamp."

Freund* has given a very good historical account of the work done in the field of phototherapy Oudin and Zimmern's book† may also be consulted. It deals in an admirable manner with treatment by X rays, radium, and by light.

In connection with the use of concentrated arc-light and violet and ultra-violet rays for the cure of lupus and for their bacteri-

* "Elements of General Radiotherapy," Rebman, London, 1904.

† "Radiotherapie," J. B. Baillière et Fils, Paris, 1913.

cidal action, a valuable paper by J. E. Barnard and H. de R. Morgan should be consulted.* These observers found that the bactericidal effect was entirely confined to a portion of the spectrum commencing just beyond the edge of the visible violet end, and extending for a short distance only. They state that the active radiations lie between the wave-lengths of 3,287 and 2,265, or, in other words, in the middle third of the ultra-violet, as seen in the spectrum of carbon. Neither the extreme ultra-violet rays nor those nearest the visible violet appeared to be active in the destruction of cultures of micro-organisms. Similarly, they found that the rays producing the inflammatory reaction in tissues exposed to light were also confined to the ultra-violet, though they were not able to assign the exact wave-length in this case, as had been possible for the bactericidal action. They found that a lamp with iron electrodes gave out a quality of light which was more active than that given out by a carbon lamp.

The mercury vapour quartz lamp of Kromayer (§ 100) seems to be the most convenient source of ultra-violet radiations. The question whether the Finsen arc-lamp or the lamp of Kromayer are the most effectual in the treatment of lupus has been much discussed, and it appears that the former is perhaps the best for deep-seated cases, and the latter better for those which are superficial. Kromayer's lamp requires much smaller currents than the arc-lamps, and is altogether easier to manage. Besides its use in lupus, it has been applied to the treatment of a large number of skin diseases, and good results have been recorded in sycosis, acne, and psoriasis, and in nævus and port-wine stain. In general, the results are due to the lively hyperæmia which is produced by the light of the Kromayer lamp, even after exposures of a few minutes.

193. **Special Effects of Coloured Light.**—Minine† of St. Petersburg and Redard of Geneva have both stated that exposure to blue light has an anæsthetic effect, under which minor operations can be performed without pain. In this country H. Hilliard‡ has reported a number of cases in which the extraction of teeth was painlessly performed af r the patients had gazed

* "The Physical Factors in Phototherapy," *British Medical Journal*, October 24, 1905.

† *Revue Internationale d'Électrothérapie*, July, 1900.

‡ *British Medical Journal*, June 17, 1905.

steadily for some minutes at an electric lamp in a blue globe held a few inches away from the eyes. The effects in Hilliard's experiments seemed to have been due rather to hypnotic action than to the production of simple anæsthesia of the parts irradiated by the coloured light. Minine's observations do not bear this interpretation, for his method consisted in the application of a fifty candle-power lamp close to the injured or painful part, and not in the exposure of the lamp to the patient's gaze. He describes several cases of joint injury and contusions in which much relief to pain was afforded, and the effusions reduced, by exposure of the injured part to the light of the blue lamp for ten or fifteen minutes. Similar results were not obtained with lamps of uncoloured glass, and from this the writer argues that the effect was not one of warmth alone. He also found the pains of gonorrhœal arthritis were much relieved by the same procedure.

Red light has been observed to have an effect in preventing suppuration in small-pox vesicles, which may simply be due to the exclusion of the blue and violet rays, as has been suggested by Finsen, who does not regard it as a specific action of the red rays. The observations of Brieger on the good effect of exposure to red light in cases of chronic ulcer, and of Motchane* in a case of noma with perforation of the cheek and lip, seem to suggest that there may be some inhibitory action upon the growth of streptococci. In the reported case, the light of a lamp of sixteen candle-power, with a red globe, was concentrated with a reflector upon the affected region, and was applied continuously for three days. At the end of that time the wounds appeared healthy, and cicatrization was in progress. No other local treatment was employed, and the writer attributed the cure to the use of the light rays, but there may have been an action from the prolonged application of heat to the part, for non-luminous heat has been found useful in some forms of superficial ulceration.

In general the psychical effect of exposure to red light is stimulating, and of exposure to blue light is calming. Rooms lighted by blue light have been used in the treatment of mental cases. M. Lumière found that the change from red to olive green as the colour of their photographic dark-rooms was followed by an improvement in the behaviour of their employés, and insubordination, which had been troublesome when their work-

* *Ann. de Médecine et Chirurgie Infantiles*, July, 1905.

rooms were lighted by red light, was found to disappear when the colour of the illumination was changed. Tadpoles kept in blue light developed normally, but when kept in red light development was retarded or arrested.

194. **The Use of Fluorescent Compounds.**—In order to augment the effect of treatment by light rays it has been suggested that some fluorescent substance should be given internally, or should be applied externally to the affected part. G. Dreyer and others have experimented with eosin and other fluorescent aniline dyes used as "sensitizers" in this way.

Professor von Tappeiner found that certain fluorescent substances, such as eosin, erythrosin, and fluorescein, which in darkness were scarcely toxic, acquired in sunlight or diffuse daylight the power of destroying infusoria and of neutralizing toxins and enzymes. Even weak solutions of the substances in question exhibited this action. Injections of eosin had a beneficial effect in the treatment of rodent ulcer, lupus, and chancre by light.

The treatment was tried by Forchhammer on twenty-three patients suffering from lupus vulgaris, and included about 350 sittings. Erythrosin—in 1 in 1,000 dilution in physiological salt solution—was injected either cutaneously or subcutaneously, according to the situation of the lupus. Four to eight hours after the injection the light treatment was applied for from fifteen to twenty minutes. The action is generally as follows: The injections are usually but little painful, and no swelling, infiltration, or tenderness follows; but within twenty-four hours of the light exposure severe pain sets in. Not infrequently the reaction of the light is like a phlegmonous process, and at times there is central necrosis. The same exposure of light without sensibilization does not produce this reaction. The therapeutic result did not stand in proportion to the severity of the reaction. In one case the treatment was followed by an inflammatory infiltration, which lasted for several months, and from time to time an erysipelas-like erythema accompanied it. The same disappointing results were obtained in lupus affecting the mucous membranes, for which fifty-four sittings were employed. Experiments were made to attempt to lessen the reaction by using weaker solutions of erythrosin, and by applying a less strong light, but this did not give satisfactory results.

F. J. Pick and K. Asahi* have found the eosin light treatment

* *Berl. klin. Woch.*, September 12, 1904.

of much value. Instead of injecting the solution, they tried the method of painting the affected surface over with a 1 per cent. solution of eosin, and this painted part was then exposed to the direct influence of the sun, the other parts of the body being protected from the rays. Crusts or scabs were first removed by ointment or other means. In all twenty-two patients were treated in this way. Twelve were suffering from lupus, one from tuberculosis cutis verrucosa, five from trichophyton (tinea), three from scrofuloderma, and one from rodent ulcer. They found that the treatment was capable of removing the inflammatory appearances in the lupus cases within a short time. The changes were most marked in hypertrophic cases. In these the affected area became flattened, and in many instances the ultimate result was absolute healing. In the other skin affections they also obtained good results. The results in tinea were obtained in very short periods. In summing up, they state that they do not yet feel inclined to speak of actual cures in lupus, and that a much longer observation is necessary before one can be sure of the ultimate results.

Béclère* has reported a case of sarcoma of the superior maxillary region in which X rays combined with quinine lactate injected in 5-grain doses an hour beforehand seemed to have a better effect than that which was obtained either by the quinine or the X rays when these were employed separately. The observation has not been confirmed in other cases.

195. **Magnetism.**—It seems to be rather doubtful whether any physiological effect has ever been observed to be due to the action of steady magnetism. Lord Crawford (then Lord Lindsay) and Mr. Cromwell F. Varley, with the help of an enormous electromagnet belonging to the former, were unable to perceive any sensation even on placing their heads between its poles. But in discussing these experiments in an address delivered at the Midland Institute at Birmingham, in October, 1883, Sir William Thomson came to the conclusion that it is just possible that there may be a magnetic sense, and, indeed, a committee of the Society for Psychical Research, who examined a large number of persons by placing their heads near the poles of an electromagnet, found three who were sensitive and were able to say when the current was on or off.

In some experiments conducted with very powerful electro-

* *Archives d'Électricité Médicale*, 1904, p. 498.

magnets by Dr. Peterson and Mr. Kennelly in Edison's laboratory, the results were entirely negative.* The subject placed his head between the poles of a large electro-magnet, which could be excited from a dynamo-machine, and the authors concluded that the human organism was not appreciably affected by the powerful magnets employed. Alternating fields (140 periods) were tried as well as steady, but no results were noticed. Professor Silvanus Thompson † has recently drawn attention to an ocular effect which can be noticed with very powerful alternating fields.

By using a coil of thick copper wire carrying 180 ampères of alternating current of 50 periods per second, he was able to observe a peculiar flickering, luminous effect in the eye when the head was introduced into the coil, and this could be perceived by almost every one of a number of observers. Probably this effect was caused by induced currents in the eyeball or in the head, but it is more likely to have been a retinal effect than an effect upon the brain. The lower periodicity used by Thompson is to be noticed, for the retina responds better to long than to short waves of current (§ 174). A similar result from an alternating electro-magnet, instead of from a simple coil of wire, had been observed by others at an earlier date, but had not received much attention. In 1902 Eugen Muller proposed to treat patients by bringing them close to the end of a large electro-magnet fed by alternating current, and it was mentioned that a flickering light could be perceived when the magnet was brought near the side of the head. W. Muller ‡ has given an account of the method.

A. von Sarbo § has used such an electro-magnetic apparatus, supplied by current at 100 volts, with infrequent alternations and of high intensity (10 to 40 ampères). He used it for various forms of neuralgia and of sciatica, lumbago, and muscular rheumatism, and states that many of his cases were cured. Improvement was obtained in a case of locomotor ataxy, with paræsthesiæ, for which latter the treatment was undertaken. In another case of the same disease gastric crises were successfully dealt with. In sleeplessness, some of which were uncomplicated cases, and others were dependent on some other

* *Electrical Review*, August 18, 1893.

† *Archives of the Roentgen Ray*, March, 1912, and November, 1912.

‡ *Zeitschrift für Elektrotherapie*, 1912, Nos. 7-8.

§ *Deutsche med. Wochenschrift*, January 8, 1903.

condition—for example, neurasthenia, hysteria, Graves' disease, etc.—two cases were not improved, while seventeen derived benefit from the treatment. The length of the treatment varied considerably, but, as a rule, patients could do without sleeping-draughts after from four to five sittings. It is doubtful whether this proposed mode of treatment is likely to survive.

CHAPTER XI

ELECTRICITY IN GENERAL DISEASES

Anæmia and debility—Neurasthenia—Diabetes—Gout—Rheumatism—Rheumatoid arthritis—Leukæmia—Lymphadenoma—Tubercle and syphilis—New growths—Carcinoma—Sarcoma—Rodent ulcer.

196. **Anæmia and Debility.**—In many forms of anæmia and in chlorosis we have to deal with simple forms of defective nutrition in which electrical stimulation suffices to bring about a change for the better. Electricity is not much resorted to for the treatment of these conditions, because good results can usually be obtained by other means. In obstinate cases where ordinary treatment does not answer satisfactorily, electrical stimulation with rhythmic currents should be tried. By these methods the metabolic processes of the patient can be so efficiently stimulated that increased appetite and vigour can be secured for the patient, with improved colour and a marked gain in weight. In chlorotic patients under these conditions the catamenia will probably be re-established. I have seen excellent results follow treatment by electric baths when anæmic patients were not doing well under iron, and consider that the results of general electrization are distinctly valuable in such cases.

When the recovery of patients after serious illnesses is slow and unsatisfactory, they should be treated by similar electrical methods. After influenza a course of general electrical treatment promotes the return of the patient's health to a normal standard. The mental depression disappears and the bodily strength returns, and the period of convalescence, which is so often prolonged in these cases, is notably shortened. I have seen a rapid disappearance of serious mental failure after influenza under general electrical treatment by the electric bath. Tripier has stated that he had never seen such rapid good effects follow any other treatment in cases of anæmia, and especially

in convalescence after acute illnesses, as those which followed general electrical stimulation.

197. **Neurasthenia.**—In neurasthenic states the methods of general rhythmic stimulation are of value, especially the electric bath, which answers very well to the indications for treatment required by these cases. If the blood-pressure is low, the static machine should be used, but not if it is high. Direct applications to the nerve-centres with the constant current (§ 181) are also useful. The condition described under the general term "neurasthenia" is a condition of general debility or of debility affecting chiefly the nervous system. Often it can be traced to some definite disturbing cause, such as mental worry or a severe illness; the digestion becomes impaired, and this keeps up a state of defective nutrition, from which it is difficult for the patient to escape.

In other cases errors or neglect in matters of diet, extending over a long time, may be the cause of the neurasthenia, and the patient himself may be quite unconscious of this. Dyspepsia is very commonly present, and should be attended to. A recent writer has found distinct changes in the character of the intestinal bacterial flora in neurasthenics, and has been able to bring about favourable results by attention to this matter.* Many people tend to become neurasthenic in the slighter degrees when their daily cares exceed a certain point, and when business matters or other troubles begin to spoil the appetite, and to interfere with proper exercise, with the regularity of meals, or with sleep, then troubles of the neurasthenic sort are likely to appear.

The original depressing cause of the illness should be found and, if possible, eliminated. If this cannot be done, no treatment will be of much use. For instance, where domestic unhappiness or discontent is a factor, one may treat in vain. Some of the cases considered to be neurasthenia are hypochondriacal, if not on the verge of insanity.

198. **Rickets.**—There is another condition of simple defect of nutrition which is benefited by general electrization. It is surprising to see how quickly children with rickets begin to improve in general health, in their powers of standing and walking, and in weight, under the stimulating effect of electrical treatment. In Italy, Sagretti and Tederchi have reported a number of cases

* F. W. Brook, "Cause and Treatment of Certain Cases of Neurasthenia," *British Medical Journal*, October 12, 1912.

of rickets cured quickly and completely by electric treatment administered by the bath method.

Severe cases of rickets referred for treatment to the electrical department at St. Bartholomew's Hospital, and treated with sinusoidal baths, have fully borne out the accounts given by those writers.

199. **Diabetes.**—Much has been written on the treatment of this disease by high-frequency methods, and cures have been reported. In most of the recorded cases a notable reduction in the daily excretion of sugar has been produced, and the patient's condition has at the same time been improved. In spite of this evidence, it remains very far from certain that even a majority of diabetics respond to high frequency by a decrease in the amount of sugar discharged daily.

Other forms of general electrization seem capable of modifying the daily discharge of sugar. I have notes of several cases in which there was a striking diminution of sugar excreted on the days on which electric baths were given, but in spite of this no real progress towards recovery was made, and it may be stated that at present the treatment of diabetes by electricity is of little value. Bonnefoy* has recorded three cases of diabetes treated by him with high-frequency currents. In two of these there was a gradual diminution of the sugar excreted, going on to its disappearance, with great general improvement in the patient's condition. In the third the treatment was interrupted on several occasions, and the results were indefinite. The patients were treated on the condenser couch, and Bonnefoy considers that daily applications should be employed.

200. **Obesity.**—Many forms of electrical stimulation have been proposed for the treatment of this condition. A satisfactory and rational method has recently been proposed by Bergonié,† in which electricity is used to produce vigorous muscular action —a method described by the French writers as "exercise electrically provoked." A full account of the details of the method has been given by Laquerrière and Delherm.‡ It consists in the application of rhythmic currents to the main muscular masses of

* See § 201 (footnote).

† "Du Travail Musculaire Électriquement Provoqué dans la Cure des Maladies par Ralentissement de Nutrition et en Particulier dans la Cure de l'Obésité," *Comptes Rendus de l'Academie des Science*, July, 1909.

‡ *Archives d'Électricité Médicale*, 1910, p. 130.

the patient, so as to provoke vigorous rhythmic muscular contractions, while, in order to augment the amount of work done, the contracting groups of muscles are loaded with sandbags. The patient reclines on a couch or in a specially designed and strong chair. The electrodes are of large area, well covered with warm, moist pads, and several pairs are used so as to influence the back muscles, the glutei, the abdominal muscles, and the muscles of the front and back of the thigh. The arms may also be included. The currents must be separately regulated for each set of electrodes, so as to obtain contractions which are in due proportion.

By reason of the extent of the electrode surfaces, there is little or no skin sensation. The sandbags may have a total weight of 80 or 100 pounds. During the treatment the patient sweats profusely, he gives off torrents of carbonic acid and water vapour; his pulse and respiration are increased; the blood-pressure is not raised, but falls as after ordinary exercise. The results of the treatment show a marked decrease in the patient's body-weight, and as the weight decreases the patient resumes his original active habits, and loses the disinclination for active exercise which is so often a marked characteristic of the obese. Before and during the treatment due attention must be paid to the general condition of the patient, particularly as regards his heart and his kidneys. The diet should be light, with a good proportion of fruit and vegetables. The treatments should last for twenty minutes when commencing, and later on may be extended to half an hour or even an hour. In a month or six weeks of treatment a loss of weight of 20 or 30 pounds may be expected. Daily treatments should be given.

201. **Gout.**—The application of ionization with salts of lithium to the treatment of gout is worthy of note, as an early instance of ionic medication.

The original suggestion is to be found in a communication of Mr. Edison's, read by Dr. Bayles of Orange, N.J., at the International Congress of Electricians held in Berlin in 1890.* Edison caused patients to dip one hand into a solution of lithium chloride of the strength of 5 per cent., and the other hand in a solution of common salt. After the passage of a current from arm to

* For an account of Edison's experiment, see Dr. Peterson's article on "Cataphoresis" in the "International System of Electrotherapeutics," by Bigelow and Massey. London: Henry Kimpton, 1902.

arm in this way lithium could be detected in the urine, and gouty symptoms were ameliorated after a prolonged course of these baths.

Guilloz* has reported two cases of chronic gout which were successfully treated by local monopolar electric baths containing lithium carbonate. He used large currents up to 200 milliampères. The positive pole was placed in the bath with the affected limb, and the negative pole, of large size, was applied to the back, or used with a second bath. The applications lasted from twenty to thirty minutes. Guilloz states that his first patient was twice treated for two severe attacks, each time with rapid good effect. The second patient also did well in spite of the fact that he continued to follow a dietary which was "of the most detestable," and that his excesses in eating and drinking were renowned ("passent à l'état légendaire").

Bordier† has shown the possibility of extracting uric acid from a patient by ionization (§ 162).

Ionization with salicylic ions is an excellent treatment for chronic gouty conditions, and is the method to be preferred. Lithium ionization can be applied simultaneously, as the salicylic ion enters by the negative pole, while lithium enters by the positive.

Thus, in treating gouty joints by salicylic ions the positive electrode can be utilized to introduce lithium or potassium ions at the same time. The usual methods of ionization are to be adopted (§ 184).

High-frequency applications have also been used for gout. Bonnefoy‡ has treated this subject very well in numerous papers, and his writings should be referred to, because of their charm of style, and because his claims are all thoroughly well supported by the careful accounts which he gives of actual cases. In general, the influence of high-frequency applications upon chronic gout is a gradual one, needing a considerable number of applications. The condenser couch is the best mode of application, and the good result obtained appears to be a consequence of the general improvement of the patient's peripheral circulation and of his nutrition.

* *Archives d'Électricité Médicale*, June, 1899.

† *Ibid.*, 1900, p. 531.

‡ "L'Arthritisme et son Traitement." J. B. Baillière et Fils, Paris, 1907.

202. **Rheumatic Affections.**—In acute rheumatism the employment of electricity is not usually required, as the medical treatment of rheumatic fever is generally satisfactory. Observations have been made, nevertheless, which seem to prove that ionic treatment of acute rheumatic joints will give prompt relief to the pain and swelling.

In the painful affections of joints and of fibrous tissues, which are so common as results of the rheumatic state, electricity is useful, both when used for its chemical effects (ionization) and for its thermal (diathermy and high-frequency). The literature dealing with the treatment of "rheumatism" by electrical methods is extensive, and dates back to the time of Remak, who devoted much thought to it. But the old literature, though very interesting in many ways, lies under the disadvantage of being rather indefinite, and the term "rheumatism" included many conditions which would now be regarded as cases of perineuritis, of gonorrhœal or septic arthritis, or of various other morbid states. Moreover, the technique of applying currents has much changed during the last few years, and the use of electrodes in the form of large thick pads bandaged on to the part under treatment has supplanted the old disc electrodes with handles, while the currents used to-day are often ten or twenty times as large as the currents formerly considered sufficient. To-day, by knowing how to apply large currents without injuring the skin, we can set up definite ionic interchanges in the depth of an affected part, or can introduce ions such as those of salicylic acid or of iodine to a sufficient depth to bring them into action in the periarticular structures or in the actual joint cavities, and we are therefore much better able to attack the problems of the electrical treatment of rheumatic conditions. Excellent results are obtained in many chronic rheumatic conditions by ionization with salicylic ions.

Diathermy also provides methods of influencing the circulation in and around a joint which are superior to anything which could be used formerly, and it is probable that the treatment of rheumatic affections by electricity is likely to yield a large percentage of successes when the ionic and thermal actions of electrical currents have been brought to bear more fully upon the treatment of these cases.

203. **Chronic Poly-Arthritis.**—The statements made about rheumatic affections in the last section apply also to the conditions

of chronic arthritis in its several forms. Gonorrhœal arthritis has been shown by Nagelschmidt to respond quickly to diathermy treatments; and he has made experiments on animals which seem to show that the interior of a joint can safely be raised to a temperature sufficiently high to arrest the growth of the gonococcus, or even to destroy it *in situ*.

In rheumatoid arthritis the results hitherto obtained from electrical treatment of the old kind leave much to be desired. Both the generalized nature of the disease and its relationship to ill-defined septic absorption make it unsuitable for local electrical applications, except in so far as it may be desirable to treat particular joints, and even in this respect we are not at present able to do very much more than to afford some slight amelioration of the pain and the swelling. In the bony changes of osteo-arthritis electrical treatment is of no particular value.

So many striking cures of rheumatoid arthritis have followed the discovery and elimination, with or without vaccine treatment, of a septic focus, and so few have followed other forms of treatment, that one's first duty is to search for some source of infection in the mouth, antrum, genital tract, or elsewhere. Dental sepsis is particularly common in rheumatoid arthritis. After the removal of the exciting cause, electrical treatment is of value to restore the damaged articular and periarticular structures.

204. **Leukæmia.**—In this disease X rays exercise a striking influence upon the cellular elements of the blood, reducing the numbers of leucocytes, and augmenting those of the red cells. Although these definite changes are produced, and suggest that X rays have valuable curative properties, it is, unfortunately, the case that we have to do here with an amelioration of symptoms rather than with a cure of the disease. The X-ray applications are most effectual when treatment is begun, but gradually they seem to lose their effect.

Treatment is given by radiations applied to the spleen, and to the ends of the long bones, the sternum and the vertebræ, in order to influence the red bone marrow, and to the lymphatic glands if these are enlarged. A group of applications to these parts, each region receiving one Sabouraud dose or less, is followed by an interval of two, three, or four weeks, and the series is then repeated. Much has been written on the X-ray treatment of

leukæmia, but, in view of the poor final results of that treatment it will be sufficient to quote one or two authorities.

Aubertin and Beaujard* have recorded two cases of leukæmia treated with X rays, with observations on the effect on the different varieties of leucocytes. One case was a myelogenous leukæmia with the classical splenomegaly, and the other a lymphatic leukæmia with marked hypertrophy of the cervical, clavicular, axillary, and inguinal glands, together with considerable enlargement of the spleen. In each case identical treatment was used: for several months there was a weekly application of the rays of the same intensity, but in the one case applied over the spleen and the myelogenous tissue of the bones, and in the other over the spleen and the lymph glands. The general state in each was rapidly ameliorated; the red blood-corpuscles in the course of three months were increased by one-third—from 2,000,000 per cubic millimetre to 3,000,000—and the leucocytes fell in the myelogenous case from 320,000 to 60,000, and in the lymphatic case from 350,000 to 10,000. In the myelogenous case there was noticed a marked increase in the leucocytosis after each of the earlier séances, reaching to 450,000, occurring three to five hours after the application of the rays, and lasting three or four hours. The polynuclear leucocytes were responsible for the principal increase. In this case the improvement in the leucocyte state was mainly qualitative; the diminution in number was established only after a long period of increase, with marked oscillations. The body-weight was maintained in spite of great reduction in the size of the spleen, the appetite was increased, albuminuria and œdema disappeared, and a feeling of well-being was established from the earlier days of the treatment. In the lymphatic case a similar increase of the leucocytes was noticed a few hours after the séance—thus, starting at 349,800, at the end of five hours they numbered 372,000, falling to 346,000 at the end of the ninth hour. By the seventh day they had fallen to 253,200, by the twentieth day to 171,600, and by the twenty-seventh to 26,000; by the beginning of the third month they had fallen to 10,000, and five days later to 3,000, at which level they remained. A qualitative amelioration did not become prominent until about a month before the onset of this leucopenia of 3,000, the polynuclears increasing little by little. The red cells increased progressively from

* *Archives Générales de Méd.*, March, p. 577.

2,130,000 to 3,100,000 ; the richness in hæmoglobin rose from 20 to 80 per cent., the spleen and the lymphatic glands diminished in size, and the general state improved.

We are not certain as to the exact way in which the X rays act in these cases of leukæmia, but probably the rays first exercise a specific action on the follicles of the spleen, and later on the bone medulla and splenic pulp tissue. David and Desplats,* in considering and analyzing the accumulated evidence, have formed the opinion that the effect in leukæmia is due to an action upon the spleen, the bone marrow, and the lymph glands, and that it is not a destructive process, but a stimulation both of the hæmopoietic activity, and also of the destructive effect on the blood-cells, which is part of the normal function of these organs. They do not consider the leucopenia to be a direct action upon the corpuscles circulating in the blood. They agree with the theory that a leucolytic or leucotoxic ferment is produced in the serum of irradiated animals, and consider this to be formed by the macrophages under the stimulus of the X rays, and not by the X-ray destruction of leucocytes.

The different degree of response to the treatment in different cases depends upon the condition of the spleen. If this has undergone degenerative and sclerotic changes, the effect of X rays is less, because the spleen in that state is not able to react favourably to the stimulus of the rays.

205. **Lymphadenoma.**—Prolonged X-ray treatment will reduce the enlarged glands in this disease, often in a striking manner, but usually relapses occur, with a fatal result.

206. **Tuberculous Diseases.**—The treatment of these affections by electricity has been extensively tried, and with fair success, so far as the relief of certain of the local manifestations of the disease are concerned. Some of these local conditions will be considered in detail in a later chapter, but it will be useful to take a general view of the situation here.

In pulmonary tuberculosis the recorded results are less satisfactory, and there is not as yet any body of convincing evidence to sustain the belief that a cure of phthisis by electricity has yet been achieved.

For most of the diseases in which our therapeutic methods are inadequate electricity has been tried, and favourable results

* "De l'Action des Rayons X dans la Leucémie," *Archives d'Électricité Médicale*, May, June, July, 1912.

have been recorded, and this is the case with pulmonary tuberculosis—a disease in which almost any rational treatment produces some amelioration in the patient's condition. If we approach the problem of the electrical treatment of tuberculosis by referring to the known physiological actions which electricity can produce, we find that we are practically limited to the effects of ionic movement, either direct or indirect, or to the direct or indirect effects of diathermal applications—that is to say, we may use ionic medication, general stimulation by interrupted currents, or applications of high frequency for their action in warming the tissues and setting up vasomotor effects, or for skin stimulation by means of effluves and sparks, and to generate ozone in the air which the patient breathes.

Of these possible procedures, the direct ionization is useful in some local tuberculous conditions; the general muscular stimulation has a good effect upon the nutritive exchanges, and so may fortify the patient's constitution.

Diathermy can be used destructively in superficial manifestations of tuberculosis, and high-frequency effluves have been recommended in pulmonary tuberculosis by several writers. The last method has been the subject of serious investigation by Doumer, Oudin, Desnoyes, Thiellé, in France; and in this country Williams has also written on the subject. The treatment preferred is that of vigorous brush discharges of the high-frequency apparatus, applied to the chest. This acts as a strong counter-irritant, and possibly, too, may liberate some ozone for the patient to breathe. The results published by Thiellé* are interesting, but they have not been followed up very much.

In lupus X rays have given ample proof of their power in promoting the healing of ulcerated surfaces, and on this account X rays are now frequently used in the treatment of this disease.

They are least successful in cases in which there is little ulceration, and it has been pointed out by Sequeira and others that certain foci of the disease may remain latent in an apparently healed area, and may break out again at a later date. The form of tubercular disease of the skin known by the name of "verruca necrogenica" responds very favourably to X-ray treatment.

High-frequency currents are also useful in lupus, particularly

* "Traitement de la Tuberculose par les Courants de Haute Fréquence" (Rouen: Megard et Cie, 1905). "Traitement de la Tuberculose Pulmonaire à Toutes ses Periodes." *Annales d'Électrobiologie*, June and July, 1912.

for the treatment of the disease in the nose or in other parts which are difficult of access with X rays. In such cases a glass vacuum electrode (§ 136) of suitable shape is very convenient. Ionic medication has been tried for lupus, and with success, by Taylor and MacKenna.* They employ zinc ionization after a preliminary treatment of the lupus nodules with liquor potassæ to denude them of the thickened epidermis, and give applications lasting for ten or twenty minutes, and repeating after a fortnight's interval, if necessary.

Tuberculous glands also respond favourably to X rays. Bergonié has reported a series of four cases treated for non-suppurating tuberculous glands, and states that he considers the action of X rays to be markedly good. All the glands treated became reduced in size, but did not disappear completely. Dovaston† has reported a case in which a large mass of glands on one side of the neck disappeared under X-ray treatment, leaving a perfectly formed neck on that side. On the other side a surgical operation for the removal of a similar mass of glands had previously been performed. The X-ray treatment occupied nine months in all. Hendrix‡ has published notes of three successful cases, and notes that the first sign of improvement was a softening of the inflammatory tissue between the glands, so that their individual contours could be felt. This was also mentioned by Dovaston. Hendrix says that the larger glands leave behind them a kind of cicatricial residue, but the smaller ones disappear entirely, so far as palpation is able to determine this. Other writers have confirmed these results.

In tuberculous joint cases, Rudis-Jicinsky has reported§ in detail a series of successful cases, and speaks highly of the value of X rays in this condition. Dr. Alex Gregor‖ has published an interesting case of a boy with a tuberculous knee-joint cured by X rays, applied in consequence of the production of improvement by X rays used for photographing the joint.

Mr. Sydney Stephenson¶ has recorded a case of tuberculosis of the conjunctiva cured by X rays after thirteen exposures; and

* *Liverpool Medico-Chirurgical Journal*, January, 1911.

† *Lancet*, February 10, 1906.

‡ *La Polyclinique* (Brussels), June 15, 1905. Abstract in *Lancet*, August 5, 1905.

§ *New York Medical Journal*, August 7, 1904.

‖ *British Medical Journal*, January 28, 1905.

¶ *Ibid.*, June 6, 1903, with figure.

W. B. de Garmo* a case of tuberculous testis treated successfully in the same way.

In a case, supposed to be tuberculous, of angular curvature of the spine in an elderly man, associated with great pain and weakness in the back, and with a lump the size of a walnut on the sacrum, I found that the application of X rays produced a marked effect upon the pain within a week, and this was followed by a gradual disappearance of the tumour on the sacrum and a consolidation of the vertebral curvature. The patient made a complete recovery, and the sacral lump had disappeared entirely at the expiry of four months from the commencement of treatment. A year later there had been no return of the trouble.

Chanoz and Lévêque† have reported three cases in which the direct current proved valuable in cases of tuberculous joint. In one of these Lévêque was himself the patient, and the results of treating his own knee for tuberculous hydrarthrosis were perfectly satisfactory to himself. In two other cases the joints treated were notably improved. The currents used ranged between 20 and 50 milliampères. The electrodes were of large surface, and were placed on either side of the affected joint.

207. **Carcinoma and Sarcoma.**—Both X rays and radium have been used extensively in the treatment of malignant diseases of all kinds, but the usual failure of both of these agents to achieve a real cure of the disease has led to disappointment, in spite of the fully-established fact that in them we have a palliative mode of treatment which is of value in many cases (see also § 190).

In looking through the published records of cases of malignant disease treated by these methods it is manifest that few of the alleged successful cases have been really complete, and this, too, in spite of the fact that hundreds of cases have been treated.

In short, while there is a quantity of evidence to support the contention that X rays and radium act beneficially in malignant disease, the amount of evidence to show that cures have resulted is lamentably meagre, and we cannot yet suggest any explanation why an agent which very commonly gives relief to some of the symptoms produced by a malignant growth should fail to give the complete relief which is really required.

It is abundantly clear that X rays have a striking influence

* *Medical Record*, April 15, 1905.

† *Archives d'Électricité Médicale*, 1903, p. 264.

in promoting the healing of superficial cancerous ulcerations, and in causing the disappearance of the lymphoid nodules which are so commonly seen as the first signs of recurrence around the scar of an amputation of the breast. The following case was one of recurrence after removal of the breast, and the patient eventually died of her disease. It represents an usual course of events in a favourable case under X rays:

When first seen, the patient had an ulceration of the right pectoral region, measuring 4 inches in one diameter and 5 inches in the other, which had come on after removal of the breast for carcinoma. Treatment with X rays was given seventeen times during two months. A few days after the treatment was commenced signs of healthy cicatrization began to appear round the margins of the ulcer. This continued to advance until the healing process had extended inwards from the margin for a distance of fully half an inch all round. The new epithelium was deeply pigmented. The centre of the wound assumed a healthy aspect, and appeared to be in process of healing all over. But at this time the patient suffered a spontaneous fracture both of the femur and the humerus from secondary deposits in the bones, and the X-ray treatment was suspended in view of the hopelessness of the future of the patient. The total number of exposures was seventeen, and many were made with the ulcerated surface covered by dressing or bandage. After the suspension of the X-ray treatment, the process of healing still went on quite steadily, until at the time of her death, a month later, there was a firm and healthy scar covering the whole surface except about 1 square inch in the centre. This portion was also a healthy healing surface, though not yet covered over by epithelium. Thus nineteen-twentieths of the area of a cancerous ulcer had healed up in three months as a consequence of X-ray applications, but there was no apparent influence upon the spread of the disease in the remote parts of the body.

With regard to the histological changes resulting from the action of the X rays on cancerous growths there is not much to be said. In a case in which a malignant tumour, after fifty exposures, was reduced to half its original size, excision was performed, and an examination of the tumour was made by Mr. Shattock, who reported to the Pathological Society of London that no degeneration of any kind or cell lysis had been induced in the carcinomatous epithelium, no phagocytic invasion of the

epithelium was in progress, and on every side the growth was in an extending condition. The clinical diminution in size of the mass and the loosening of its deep connections were difficult to explain ; possibly they were due to the disappearance of a subinflammatory œdema.

In a patient under my own care a course of X-ray applications was given soon after the removal of enlarged glands from the cervical region. The breast had been removed on a previous occasion. After treatment by X rays had been continued for two months some thickening was felt underneath the scar of the second operation wound. An operation was performed, and the doubtful region was excised. A microscopical examination revealed fibrous tissue containing a few cells of suspicious character, but not of such a kind as to enable a diagnosis of carcinoma to be made with any certainty. It is interesting to remark that the tissues removed at the operation which preceded the use of X rays were distinctly carcinomatous, with abundance of epithelial elements, and it is therefore possible that the X-ray applications may have altered the character of the recurring growth in a beneficial way, although they had not succeeded in preventing recurrence altogether.

It has been suggested that the best mode of employing X rays in malignant disease is to commence at an early date after the removal of the growth by operation, before any evidence of recurrence has shown itself, in the hope of preventing recurrence by destroying any microscopical foci of disease which may have escaped removal. Not much evidence has yet been collected as to the value of this procedure.

Until some working hypothesis can be formulated as to the mode of action of X rays and of radium upon the cancerous process we can do very little but grope in the dark.

After all, when one considers how often a total ablation of the malignant tumour proves a failure, one must recognize that treatments such as irradiations, which are manifestly less thorough than complete removal, are bound to fail, unless the irradiations can set up some change in the composition of the blood-plasma which will render the rest of the patient immune to the malignant process. That X rays and radium may have some such general influence is not inconceivable, and, if so, then it might prove to be useful to radiate not merely the affected part or tumour, but to apply the action of the X rays or the radium to extensive

areas of the body, or perhaps to the whole patient, by a series of applications, each taking in a certain part of the surface. This procedure would permit the use of very much larger doses of treatment, and would avoid the production of dermatitis, which so often occurs in the present method of treatment by X rays directed solely to the affected part.

In sarcoma the effects of X rays may at first appear strikingly successful.

I have myself observed an instance of complete disappearance of a rapidly-growing round-celled sarcoma of the jaw, in which the patient, after remaining free from recurrence for a twelvemonth, once more began to show a suspicious thickening in the region of the scar, followed later by evidence of deep recurrence, which ultimately proved fatal. Thus we have in sarcoma, as in carcinoma, the strange phenomenon of the profound influence exercised by the rays, with a strange insufficiency so far as final cure is concerned.

W. B. Coley,* reporting on sixty-eight cases of sarcoma treated by X rays, states that in six cases complete disappearance was observed, but in every one of them there was a recurrence within a few months from the time of the disappearance of the disease. In two of these cases the recurrent growths subsequently disappeared when injections of the mixed toxins of erysipelas and *Bacillus prodigiosus* were added to the X-ray treatment. These two cases remained well, although in one nearly two and a half years, and in the other one year, had elapsed since the disappearance of the last recurrent growth.

Coley's paper gives detailed histories of a number of interesting cases. He tells us that he had inquired into the subsequent fate of several reported cures of sarcoma, and had found that in general the patients had afterwards died, even although the X rays had caused complete disappearance of undoubted sarcomatous tumours. He concludes his paper with the following remarks, which will be endorsed by all who have had sufficient experience in this class of case :

"The results of the treatment of sarcoma with the X rays thus far have shown :

"First, that the great majority of cases are but little affected by the use of the X rays.

"Second, that in a certain small proportion of cases the tumour

* *Archives of Physiological Therapy*, April, 1906.

decreases rapidly in size and, in a few instances, may totally disappear.

"Third, that in all of the cases so far observed, with one exception, there has been either local or general recurrence, although in some few cases life has undoubtedly been considerably prolonged.

"Fourth, the very small percentage of cases in which the tumour has disappeared and the almost universal tendency to early recurrence even in these cases are sufficient reasons for never advocating the method except in inoperable or recurrent cases."

The action of radium in sarcoma is very similar.

The treatment of cancerous growths by electrolysis has been proposed, to produce sloughing of parts of a cancer, when nothing else can be done.

For many years G. Betton Massey,* of Philadelphia, has employed ionization (§ 184) in cancer cases. In his method actual destruction of the central portions of a superficial malignant growth is combined with a diffusion of ions of a metal such as zinc or mercury into the peripheral parts, and he has been able to observe that the treatment has an undoubted effect in arresting the malignant growth in a zone lying outside the portion which has been destroyed by sloughing as a result of the treatment. Dr. Massey attributes this to the action of the metallic ions which have diffused away from the electrode, and he lays especial stress upon the need for allowing a sufficient duration of time to the electrolytic treatment, in order to permit of a sufficient diffusion, as this is a comparatively slow process.

The currents used have ranged from 350 to 1,800 milliampères, the duration of the application lasting one hour, or even longer.

In a recent paper Dr. Massey states that about 20 per cent. of his cases have been satisfactorily cured. A. Granger,† of New Orleans, endorses Dr. Massey's method, and says, further that as a cure or a palliative for malignant disease within the mouth it has proved of especial value.

208. **Rodent Ulcer.**—The treatment of rodent ulcer by X rays has given many satisfactory cures, and the treatment by radium

* "The Treatment of Cancer by Electrical Destruction and Regional Sterilization through the Cataphoric Diffusion of the Electrolytic Salts of Mercury and Zinc" ("An International System of Electrotherapeutics." London, Henry Kimpton, 1902).

† Transactions of the American Electrotherapeutic Association, 1904.

is probably even more successful. But neither X rays nor radium are invariably successful, and in the later stages of the disease this is especially true.

Another electrical method of treating rodent ulcer is ionization with ions of zinc. Leduc first indicated this method, and it has been developed in this country by the writer, in whose hands it has already been successful in a number of cases. There have also been many failures, and in general it may be said that zinc ionization answers best in early cases, and least well in cases which have relapsed after other treatments, and in large ulcers of long standing. Details of the operative procedure will be found in a paper* in the *Lancet*, with notes of seven cases.

The ionic method is theoretically a good one, and the failures are probably to be ascribed to the imperfect penetration of the zinc ions, which are precipitated in an insoluble form as zinc phosphate when they come into contact with the plasma. Some other ion with better powers of penetration must be sought for if the treatment of rodent ulcer by ionization is to become the method of choice. The details of the treatment with zinc ions are as follows: The surface of the ulcer having been freed from all crusts and cleaned, it is covered with a few layers of lint cut to fit its area, and these are soaked in a 2 per cent. solution of zinc sulphate or zinc chloride. A zinc rod or button connected to the positive pole is applied to this, and the circuit completed by an ordinary flat plate electrode placed upon any convenient part of the patient's body. The current is then turned on, and slowly raised to 5 or 10 milliampères, and maintained for a quarter of an hour. The exact magnitude of the current should depend upon the size of the ulcer. Leduc has suggested 2 or 3 milliampères per square centimetre. The pain of the application can be diminished by a very gradual increase of the current at the commencement, or by a preliminary introduction of cocaine by a similar ionic procedure, using a pad moistened with 1 per cent. cocaine solution.

The zinc ions seem to remain in the cells of the affected part for some time, or at least the effect set up by the application continues for a considerable time afterwards. For instance, in one of my patients, where it was evident on September 6 that the pearly edge of the rodent ulcer treated on August 30 had not

* Lewis Jones, "Some New Lines of Work in Electrotherapeutics," *Lancet*, October 28, 1905.

disappeared, it was decided to allow another week to pass before repeating the application, and a week later this edge had become very much less definite, although nothing further in the way of zinc electrolysis had been done to it. Another patient, writing a month after the electrolysis, stated that the spot was smaller, but not gone, but after another month, without further electrolysis, the spot had so completely disappeared that its exact site was difficult to locate. The appearance of the rodent ulcer at the end of the application is peculiar. Where the zinc ions have penetrated the epidermis has a milk-white look, but this white colour does not mean that there is going to be any necrosis of tissue, and seems merely to be the proper appearance of a tissue impregnated with zinc ions. The white colour slowly fades away, and leaves the surface rather sore for a week or more. During this period a little zinc lotion or ointment may be applied, but there need be no question of repeating the ionization for a fortnight. It may then be repeated if the appearances are not quite satisfactory. Some cases are completely cleared up by one ionization, but more often two or three are required.

CHAPTER XII

THE NERVOUS SYSTEM—THE PERIPHERAL NERVES

Electricity in diagnosis—The motor points—Relation of spinal nerve roots to muscles—Practical testing—The reaction of degeneration—The use of condensers—Treatment of paralysis—Special nerve injuries and diseases—Neuritis—Neuralgia—Sciatica—Sprengel's deformity.

209. **Electrical Testing of Nerves and Muscles.**—The examination of the electrical reactions of the muscles is often of great assistance in the diagnosis of cases of paralysis. An electrical test often gives distinct evidence in cases where without it one could only guess at the morbid condition of the affected parts. The following history affords a useful instance of its value : A patient had an accident with broken glass, cutting himself in several places. As the ulnar nerve showed signs of injury, the wounds were carefully examined. In two of them near the wrist the nerve was found to be divided, and was sutured. In the other wounds the nerve could not be seen, and it was thought to have escaped injury at those points. No electrical test was made at the time. Some weeks later an electrical examination was sought, as the limb remained paralyzed. It was then found that the flexor carpi ulnaris showed a reaction of degeneration, which proved that the nerve had undoubtedly been divided in another of the wounds, which was above the elbow. On exploration the nerve was found to be divided at that point, was joined, and the patient made a good recovery. Another patient with a wound of the hypothenar eminence from a broken pane of glass complained of vague pains and weakness in the hand, and was shown by electrical testing to have a reaction of degeneration limited to certain of the intrinsic muscles of the hand, caused by division of the ulnar nerve in the centre of the palm by a spicule of glass which had penetrated deeply.

Electrical testing depends upon the fact that the normal reactions may become changed as a result of disease or injury.

The changes looked for are changes in the visible responses given by the muscles. As there may be changes in the behaviour of the muscles either to interrupted or continuous currents, both forms of electrical excitation are used in the examination of a muscle. The testing is usually done with the active electrode (§ 67) applied to the muscle itself, at or near to its motor point. The testing electrode may also be applied to the nerve trunks, at a distance from the muscles, to determine their power of conducting motor impulses, their conductivity being shown by the movements of the muscles to which they are distributed; but it is to the muscles that the testing electrode is generally applied, as the individual contractions of each muscle can be better seen in this way.

In testing a muscle the electrodes required are the indifferent electrode (§ 67) and the electrode handle with "closing" key (Fig. 51). The former is to be placed over any convenient and remote part of the body; thus the patient may hold it against his chest, or it may be slipped down the back of the neck, so as to be held in place by the pressure of the clothing, or with a patient lying down it can be placed beneath the hips, or finally, if the patient is lying on his face it may be placed over the sacrum. In any case it must touch the skin with even and firm pressure throughout the process of testing. Both the electrodes and the surface of the body concerned must be well moistened with warm salt and water, and the more thoroughly this preliminary moistening is done the more satisfactory will the testing be. Instead of using a key in the handle of the electrode, the current may be led through a metronome (Fig. 56), which then makes and breaks the current in a very convenient manner.

In testing the intrinsic muscles of the hands and feet, and with a few other muscles, as, for example, the deltoid, it may be convenient to apply both electrodes over the part in such a way as to cause the current to pass right through the region under test; thus the interossei are most easily thrown into action with the indifferent electrode under the palm and the active electrode on the dorsal aspect of the hand.

Again, for testing the muscles of the legs a very good position is for the patient to lie prone, with the indifferent electrode over the lumbar spine, the leg to be tested being flexed and supported vertically. In this position all the leg muscles can be reached,

and the foot is free to move in any direction in response to the contractions of the muscles as they are tested.

The active electrode or testing electrode should be of small surface ; one which is one inch in diameter is very suitable. Its surface may be slightly convex. Standard sizes for the electrodes used in testing have been proposed—viz., 100 square centimetres for the indifferent electrode, and 1 square centimetre for the active electrode.

210. **The Motor Points.**—These are the points to which the testing electrode should be applied in order to set up a contraction most easily in the subjacent muscle, or they are points at which motor nerve trunks can be easily reached. They represent positions at which a maximum effect can be produced by a given current, and a good knowledge of the motor points enables one to carry out a test with comparatively weak currents, and therefore with the least amount of discomfort to the patient. Many diagrams of the motor points have been prepared, most of them being based upon von Ziemssen's plates (see Plates I.-VI. at the end of this volume).

These plates were prepared by exploration of the surface with a testing electrode, and marking the points as they were found. Dissections on the dead body show that the most excitable spots correspond to points at which the main nerve supply enters the muscle.

The motor points are not quite constant for different individuals ; their exact places vary a little in different cases, but not so greatly as to diminish the value of knowing their positions. The best position of the electrode can be readily found by moving it about in the neighbourhood of the usual position of the motor point of any particular muscle until the vigour of the contraction shows that the exact spot has been touched. The ease with which the motor points can be found depends a great deal upon the amount of subcutaneous fat present, and the examination of the deeper muscles is always more difficult than the superficial layer ; indeed, in the case of some of the deep muscles it is almost impossible to produce a contraction limited to the muscle sought, because the diffusion of the current throws the neighbouring superficial muscles into action, and obscures the result. It is important to place the patient's limb in a good position, so that any muscular movement looked for may be readily seen ; the muscles must be lax ; the limb should be supported by the hand

of the operator, and not lying flat upon the table or couch. It is best to begin with a current which is enough to throw the muscle into strong contraction, and to apply it only for a very brief moment at a time; in this way the process of testing will be sooner over. It is well always to try the strength of the current on one's self before touching the patient (§ 212).

It is assumed that the action of the individual muscles is known, so that when a contraction is produced it can be referred to its proper muscle. Besides watching for and seeing the movement produced by the contracting muscle, one may place a finger upon the tendon to feel any movement, or one may see slight movements in the fibres of the muscle itself even when they are too feeble to move the limb.

211. **Relation of Spinal Nerve Roots to Muscles.**—Frequently it happens that paralysis affects a group of muscles, and one may wish to trace back their nerve supply to the spinal roots. For example, the distribution of a paralysis affecting some of the muscles of the hand might enable us to distinguish between a lesion of the trunk of the median nerve on the one hand and a lesion of the first dorsal root on the other. In the latter case the whole of the thenar and hypothenar eminences, and all the lumbricales and interossei would be involved; in the former case many of these muscles would escape—namely, the hypothenar muscles, the interossei, the two inner lumbricales, the adductor pollicis, and the inner half of the flexor brevis, all of which are supplied by the ulnar nerve.

Many writers have given lists of the muscles of the upper limb with the segmental arrangement of their nerve supply, and although these lists present minor differences they agree in a general way with one another. In the *Medical Annual* for 1904, under the heading "Brachial Plexus," will be found a useful paper by William Thorburn. After comparing the views of different anatomists, he gives a table from which the following list is compiled:

Nerve Roots—*Fourth Cervical.*—The spinati (and probably the rhomboids and teres minor).

Fifth Cervical.—Deltoid, biceps, brachialis anticus, supinator longus and brevis (coraco-brachialis very probably).

Sixth Cervical.—Subscapularis, pronator teres, and quadratus, teres major, latissimus dorsi, pectoralis major (part), and minor (probably), serratus magnus, radial extensors of wrist.

Seventh Cervical.—Triceps, ulnar extensor of wrist, extensors of fingers.

Eighth Cervical.—Flexors of wrist and of fingers.

First Dorsal.—Intrinsics of hand.

The flexors of the wrist and the extensors of the fingers are thus distributed by Sherren. In the lower limb the segmental arrangement is less clearly known, but it is most probable that the third lumbar segment supplies the psoas and iliacus, and the adductors of the thigh. The fourth lumbar supplies the quadriceps, the sartorius, and the tibialis anticus, and the fifth lumbar the extensors of the toes and the extensor proprius pollicis; while the muscles of the calf and the intrinsic foot muscles must be assigned to the first sacral segment. The perineal muscles (levator ani, sphincters, etc.) are probably supplied from the third sacral, and the glutei and hamstrings from the second sacral segment (Sherren).

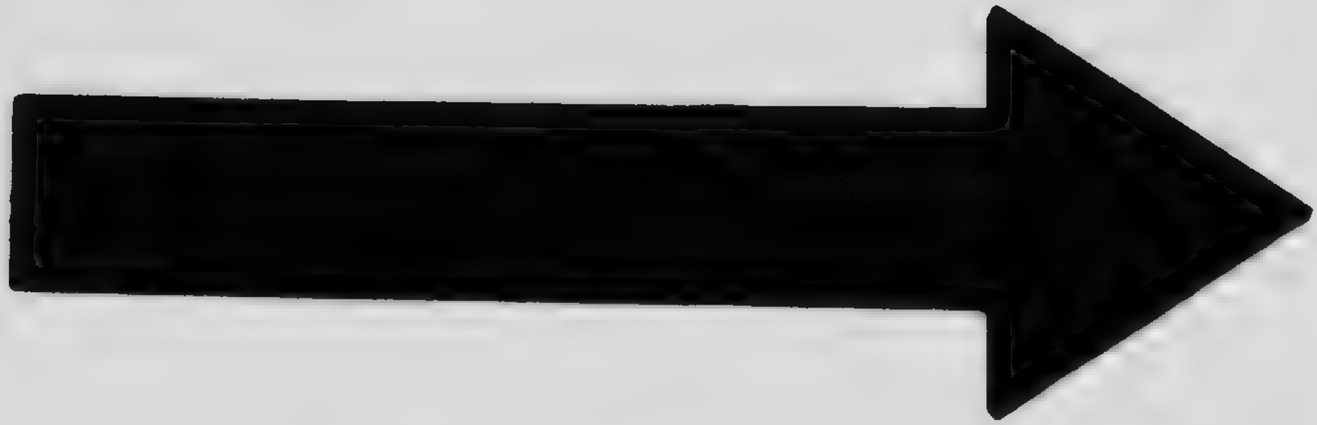
The segmental distribution of the sensory nerves has been worked out by Head and others, and diagrams of the body surface showing the segmental areas are to be found in most of the textbooks of nervous diseases.* Dr. Tooth's diagrams are given in the Appendix. Dr. Tooth states that these diagrams have been prepared from cases occurring in the practice of the National Hospital for the Paralyzed and Epileptic, and that they have been to a large extent verified by operation or post-mortem examination.

212. **Practical Testing.**—When a fair degree of skill in finding the motor points has been acquired, the chief difficulties of testing the reactions of a patient's muscles will disappear. Nothing is so useful for the student as to practise frequently upon his own muscles. Half an hour spent in picking out the motor points, and in observing the relative sensitiveness of the skin in different parts of the body, and in noting the effect of a thorough moistening of the skin before applying the testing current, will well repay a beginner.

It is a useful rule always to apply the current to one's self at the commencement of a test. The patient feels reassured if he sees this done, and the chance of the current being too strong is decidedly lessened. The easiest method is as follows:

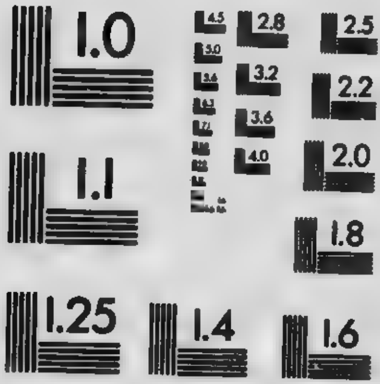
Place the indifferent electrode in position upon the patient,

* See H. H. Tooth, "The Segmental Spinal Sensory Areas clinically considered," St. Bartholomew's Hospital Reports, 1905.



MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



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and moisten the skin of the part to be tested; then grasp that part with one hand, and apply the testing electrode to the back of the hand which is holding the patient; then on closing the key the current will pass to the patient through the hand of the operator, who will be able to judge of the strength of the current by the sensation produced. One should commence testing with interrupted currents, and finish with continuous. There is seldom need to use very strong currents. Short applications mean less pain to the patient.

When testing with the continuous current begin with about 20 volts for the limbs, or half that pressure for the face. Let the testing electrode be the kathode, and note whether a closing contraction is visible, and if none is seen, increase the current until it appears, observing the readings of the galvanometer. When the closing contraction is obtained, note the effect of moving the electrode, in order to find the most effective spot for stimulating the muscle, compare the ACC with KCC (§ 167), and take especial notice of the nature of the contraction to see whether it be quick or sluggish. Next compare the contractions obtained by direct stimulation of the muscle with the effect of stimulating it indirectly through its nerve trunk. Lastly, note the results methodically in the form of a report.

When the affected parts can be compared with the corresponding region on the opposite and sound side of the body, it is not difficult to perceive changes in the electrical reactions. When the disease is bilateral this is not so simple, and one must depend to a certain extent upon previous experience, and upon comparisons with one's own reactions; but, wherever possible, the comparison of the affected muscles with their fellows of the opposite side of the body is a matter of the first importance.

The testing of muscles in children with infantile paralysis is a painful process for the little patients and difficult for the operator, because usually there are a large number of muscles—often the whole of both lower limbs—which must be examined, and the child cannot keep still.

Bergonié,* in an admirable paper on the diagnosis and treatment of infantile paralysis, has suggested a method by which these tests can be carried out with little or no distress to the child, and it is one which should certainly be adopted. Fig. 161 shows how it is done. Large electrodes and large, thick cloths

* *Le Journal Médical Français*, April 25, 1911.

are made use of, as in the procedure of ionization, in order to diffuse the current widely at the points of entry, and so to reduce the skin sensations. One of these electrodes is arranged so as to enwrap the whole foot, and the other is placed under the buttocks, and should be broad enough to include the whole of this region. The induction-coil current is then applied through the metronome, and traverses the whole limb, and the different muscles are watched, when contractions can be seen and recognized in all the muscles which have not lost their power of response to coil currents (faradism). The child, if encouraged, will be able to endure the currents so applied without distress or struggles. The direct current is then substituted for the interrupted current, and the muscles again watched, when the

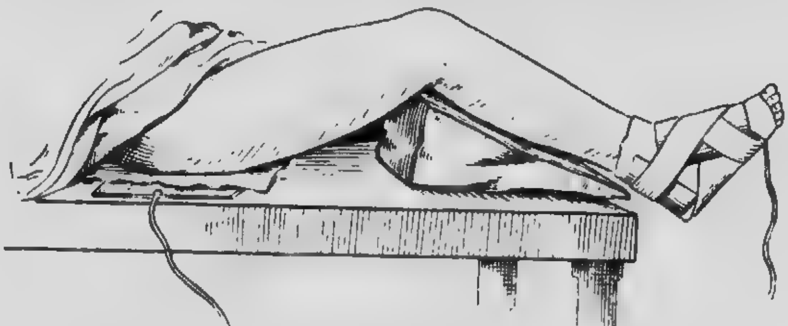


FIG. 161.—BERGONIÉ'S METHOD OF TESTING LOWER LIMB MUSCLES.

responses, whether sluggish or normal in character, can be observed and noted. This will usually suffice to complete the testing.

213. **Changes in the Electrical Reactions.**—The changes which may be found in the reactions as the result of disease or injury are classified as follows:

1. Quantitative changes or changes in the amount or quantity of response to stimuli, the character or quality of the reactions not being otherwise changed.

This includes simple increase of excitability and simple decrease of excitability to coil and cells, changes which are usually spoken of as *quantitative* changes.

2. Qualitative changes or changes in the nature or quality of the reactions. These include the reaction of degeneration, both complete and partial, the myotonic reaction, the myasthenic reaction, etc.

3. The condition of total loss of all visible contractions, both to coil and to cells, must also be considered.

214. **Quantitative Changes.**—In unilateral disease increased or decreased excitability is shown by differences in the behaviour of the two sides. If the normal side be used as a standard for purposes of comparison, an increase of excitability will be inferred if the minimal contraction shows itself with a lesser current on the affected side. If both sides are affected, then an increased excitability may be inferred if the minimal contraction is seen with currents which are weaker than those which the operator has learnt to recognize as usual in healthy people. The diagnostic value of small qualitative changes is not very great, so happily their determination is not of the first importance.

The recognition of increased or decreased irritability is easy when the increase or decrease is considerable, but to diagnose slight increase or slight decrease demands great care, as there are many disturbing factors to be guarded against. Careful attention to galvanometer readings is the best guide, but even then one has to consider the differences which may depend upon the place of the testing electrode, for a slight movement away from the motor point will make the current less effective, and so will simulate a decrease of irritability. Again, unequal pressure of the electrode, when comparing two points, may cause an apparent difference in irritability, for with increased pressure the electrode is pushed nearer to the nerve or muscle, and is rendered more effective. The resistance of the skin may also vary during a test, and as it usually falls while the testing is in progress, this may complicate matters. Sometimes the resistance in a paralyzed limb is much increased through alterations in the condition of the skin which covers it.

Increased irritability occurs usually in those conditions in which increased reflexes are found. Both signify increase of irritability in the central nervous system. It is observed in chronic myelitis, in degeneration of the lateral columns, and in hemiplegia, also in tetany, in which disease it becomes a prominent feature.

Diminished irritability occurs in many diseases. It is seen in the milder forms of those injuries and diseases which show qualitative changes when they are more severe—for example, in acute anterior poliomyelitis a reaction of degeneration will be

found in some of the paralyzed muscles, while others will only show simple decrease of irritability. In neuritis, too, both traumatic and other, one may see either qualitative or quantitative changes, according as the attack is severe or mild.

Simple fatigue may cause decreased irritability. In myasthenia gravis, decreased irritability, coming on during the progress of the testing, is a striking symptom. A progressive decrease in the response to a series of stimuli may often be noted in muscles whose reactions are enfeebled.

The electrical properties of the testing circuit have a decided influence upon the apparent excitability of nerve and muscle, and this introduces fresh disturbing factors when the results of testing with one apparatus are compared with those of a different one. Dubois* has shown that the presence of much self-induction in the testing circuit lowers the stimulating effect of the current by retarding the rate of growth of the current at the period of closure. A stimulus is effective in proportion to the suddenness with which the current rises to its maximum, and the greater the self-induction of the circuit the slower this rise becomes.

215. **Qualitative Changes—The Reaction of Degeneration.**—This term was introduced by Erb to signify the altered electrical reactions which occur in the nerves and muscles under certain definite morbid conditions, the most characteristic feature being that there is an alteration in the quality of the response which the muscles make to the continuous current, the contraction provoked being a slow and sluggish one, differing greatly in its character and appearance from the rapid twitch given by a normal healthy muscle.

The reaction of degeneration is characterized by the loss of all excitability in the nerves and of the excitability to brief interrupted currents in the muscles, whilst the excitability of the latter to longer-lasting currents remains, and is sometimes notably increased, but undergoes a definite and peculiar modification, the contraction set up being slow or "sluggish" (Fig. 162).

This reaction of degeneration (usually symbolized by the abbreviation RD) is of very great importance, and its value consists in the fact that when it is present we can diagnose a lesion in a certain part of the nervous tract. A lesion causing the reaction of degeneration must be situated in the lower

* *Arch. d'Électricité Médicale*, 1898, p. 1.

neuron, either in the grey matter of the anterior horn in the cells from which the nerve fibre starts, or else somewhere in the course of the nerve fibres passing from there to the muscle. The reaction of degeneration does not follow lesions of the upper neuron, nor does it follow affections which are confined to the muscle fibres proper (idiopathic muscular atrophies).

In RD the irritability of the nerve disappears entirely, and therefore stimulation of it, whether by interrupted or continuous currents, has no effect; the muscle, on the other hand, retains its irritability to certain forms of electric stimulation. Though it does not react to rapidly interrupted currents, it can react to a mechanical shock, or to a current whose duration is not too brief. It differs from a curarized muscle, for this will still react to brief interrupted currents directly applied, and therefore the loss of irritability seen in a muscle with the reaction of degeneration signifies something more than a failure of the intra-muscular nerve endings, and probably means that a trophic change has occurred in the muscle protoplasm. Interpreted in the light of Ioteyko's researches (§ 167), it would signify a failure of the striated elements of the muscle, and a survival of the sarcoplasmic components. The production of ACC more easily than KCC, which may often be seen in the reaction of degeneration, is a further evidence of the change which has occurred. This alteration of the relative effect of the poles is not an essential part of the reaction of degeneration, for it is not constantly present, although it was formerly thought to be an invariable concomitant of the reaction of degeneration. Another important alteration is that the irritability of the muscle to the continuous current may be greater than in health, strong contractions being set up in the affected muscles by currents which are too weak to produce any visible movement in the neighbouring healthy muscles.

It is only in fairly recent cases that this exaltation of muscular irritability is manifested, and in most cases of RD of long standing a progressive decrease of irritability in the affected muscles is observed.

216. **The Longitudinal Reaction.**—In muscles showing a reaction of degeneration it will be found that a contraction is more easily elicited when the testing electrode is applied at the distal end of the muscle than when it is at the motor point. This effect was first noticed by Remak in 1876 in a case of wrist-drop

due to lead, but it has only received attention in recent years, and has been described by Doumer as the "longitudinal reaction." Its meaning is that the motor point has lost its importance, the longitudinal reaction being produced by direct stimulation of the muscular fibres, the reaction at the motor point by stimulation of the muscle through its nerves.

The longitudinal reaction is of great utility in electrical testing, and an examination for it should never be omitted. It affords a means of eliciting a contraction in old-standing or severe cases when the irritability of the muscle is so reduced that contractions are difficult to obtain with the electrode on the motor point. It also helps to confirm a diagnosis of reaction of degeneration when the test applied at the motor point leaves the operator doubtful as to whether it is "sluggish" or not. If in such a doubtful case the test with the electrode on the distal tendon gives a stronger and slower contraction than can be obtained at the motor point it is certain that degenerative changes exist in the muscle.

Again, it may happen that the contraction obtained with the electrode on the motor point is passably quick, while that obtained distally is decidedly slow. This probably signifies a degree of injury which is less severe than one giving a sluggish movement for both situations of the testing electrode, and it is a phenomenon which may often be observed if looked for.

217. **Partial Reaction of Degeneration.**—This term is applied to cases in which some degree of contractility for brief interrupted currents is present, although there is decided sluggishness of contraction of the muscle for the continuous current.

The existence of "partial RD" makes it important in testing always to confirm the results of the induction-coil test by the application of the continuous current test. If partial RD be present there is usually a perceptible alteration in the coil reactions, but this may be overlooked, and in that case conclusions drawn from the presence of coil reactions alone would seriously mislead. Between partial RD and complete RD there are various degrees of alteration. The sluggishness of contraction may vary within wide limits: the reaction to the coil may be very faint or fairly strong.

Since its formulation by Erb the group of signs which go to make up the reaction of degeneration has held its ground as the central feature of electrical testing for a generation, but the

whole situation is badly in need of further analysis. So long as the recognition of "sluggishness" is a matter of the operator's judgment the test by Erb's method will be unsatisfactory. The preceding paragraphs have indicated that it may be very difficult in certain cases to determine whether "sluggishness" is present or not. Also the nature of the interrupted current employed in testing is in need of revision. Indeed, it is possible by employing a slow interrupted current, with long waves, to produce a condition like that of tetanus in a muscle which is the seat of a marked reaction of degeneration, and gives no response at all to interrupted currents of the kind generally used with short wave lengths (§ 61).

218. **Practical Difficulties in Testing.**—Those who are familiar with electrical testing are well aware of the fact that notable variations in degree are to be seen in the reaction of degeneration. Some of these are certainly due to a general degradation of the state of the muscle in cases of long standing, which makes the contractions more difficult to see, and deprives them of some of the sharpness of character which one might expect. Examples of this kind in which the RD can still be observed, but which are not good cases for the demonstration of typical RD, are common enough. The polar change with predominance of ACC over KCC is referred to by Professor Erb as one of the most constant phenomena in medicine, but, in the opinion of many workers, the phenomenon is so inconstant a part of the reaction of degeneration as to be without diagnostic value. It is possible that the relative order of appearance of ACC and KCC may be influenced by chance positions of the testing electrode. See Fig. 156 for the virtual polarity of parts around an electrode. Thus a positive electrode near to a motor point, but not exactly over it, might set up a virtual negative polarity at the motor point, and *vice versa*. Again, the degree of sluggishness, or, in other words, the duration of the contraction produced in muscles by the closure of the current from the cells, varies within a wide range, so that at times one may see a contraction so long and slow as to resemble a veritable peristalsis of unstriped muscle, while in other cases it is only after a careful comparison with sound muscles that one can at last determine whether the contraction is or is not to be called slow.

There are two directions along which the study of electrical reactions should be prosecuted. One of these is by the graphic

method, using a recording apparatus to trace the curves of the muscular movements, as has been done by Mendelssohn. The apparatus used is a combination of key electrode with a tambour for receiving the impulse of the contracting muscle, and transmitting it to a revolving drum. It was described by Radiguet, and is made by M. Boulitte, 7, Rue Linné, Paris. The other is along the line of using impulses of varying durations, and observing the minimum durations needed to set up the muscular contractions (§ 223).

219. **Curves of Muscles with RD.**—The graphic method has taught us that there may be degrees of sluggishness in the contractions of muscles showing RD. Fig. 162, taken from an article by Mendelssohn,* illustrates this. Curve 1 is the curve of a normal muscle. Curves 2, 3, 4 are those of muscles in different stages of

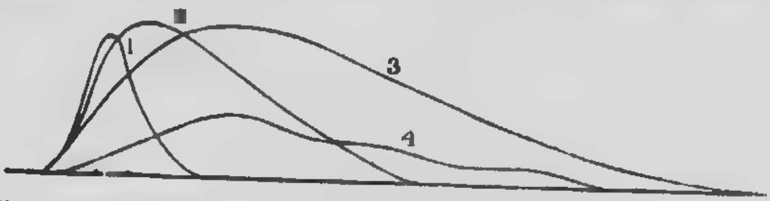


FIG. 162.—MUSCLE CURVES IN VARIOUS STAGES OF THE REACTION OF DEGENERATION.

1, Normal curve; 2, 3, and 4, progressive stages of degeneration.

the reaction of degeneration, and they show that the degree of sluggishness may vary within rather wide limits. That this is so is often to be recognized by the unaided eye. Indeed, it may happen that the response of a muscle tested by the continuous current may seem to be on the border line between quick and slow, and it may require careful comparison with neighbouring muscles before one can venture to state that it is sluggish or not sluggish. This uncertainty is a difficulty in practical testing. It can be cleared up by applying the longitudinal reaction (§ 216), but it does not occur as an important point when the method of testing by condenser discharges is made use of, as in that method the presence or absence of visible contraction is the sign looked for. Even in health there are differences in the rates of contraction of different muscles.

* Boruttau and Mann, "Handbuch der Ges. Mediz. Anwendungen der Elektrizität," vol. ii., p. 135, Leipzig, 1911.

220. **Conditions which lead to the Reaction of Degeneration.**—We have already seen that RD follows damage to the lower neuron—that is to say, to that part of the course of a motor fibre which commences at the ganglion cell of the nucleus of origin, or its equivalent in the anterior cornu of the cord, and is continued down as the nerve fibre to the motor end-plate beneath the sarcolemma of its muscle, and a certain degree of severity in the damage is necessary to produce it. RD is therefore found after division, injury, or disease of the motor nerve trunks, of the ganglion cells in the anterior cornu of the cord, or of the corresponding nuclei of origin of the cranial nerves. Under one or other of these morbid states can be grouped pressure palsies of all kinds, division or contusion of nerves, different forms of toxic or other neuritis, anterior poliomyelitis, both acute and chronic, also acute and chronic myelitis. The reaction of degeneration is not found in the paralysis of cerebral disease, except when the implication of the nuclei of origin or of the nerve trunks of the cranial motor nerves produces a reaction of degeneration in the muscles which they supply ; nor does it occur in diseases limited to the white matter of the cord, nor in hysterical paralysis.

221. **The Course of the Reaction of Degeneration.**—After a nerve-trunk injury the course of events and the times at which they take place will naturally depend upon the nature of the injury, and on its severity. It is generally stated that after section of a nerve there will be a transient period of increased irritability. This is immediately followed by a progressive decrease, and by the end of a week or ten days the irritability of the nerve will be completely abolished, and will remain so until recovery takes place.

After section of a nerve trunk the affected muscles cease to respond to the interrupted current in from four to seven days, and Sherren* states that at about the tenth day it becomes difficult to obtain any response to stimulation with the constant current, and that the characteristic sluggish contraction with polar reversal begins to make its appearance about this time. This sluggish response persists for a long time, but gradually becomes less easy to provoke, and may finally disappear. It may persist for several years. In cases which are sutured and recover it usually happens that the power of voluntary move-

* "Injuries of Nerves and their Treatmen t." J. Nisbet, 1908.

ment will return some little time before the response to electrical stimuli. A slight response to coil currents is the first change to be noticed in the reactions, and this will be noted when the response to the battery currents is still sluggish and feeble. Sometimes the muscle will begin to show a coil reaction, when stimulated through its nerve trunk, before it responds to a similar stimulus applied directly to the muscular fibres, and it may show a sluggish response to the longitudinal test, and a quick one at the motor point.

222. **Prognosis in the Reaction of Degeneration.**—The student must not fall into the error of looking upon the occurrence of a reaction of degeneration as in itself indicative of irreparable mischief, and conversely normal reactions may be consistent with absolutely incurable lesions, involving complete paralysis. It is quite a common experience to see a complete recovery with a return of normal reactions, and of normal voluntary power in muscles which have shown a reaction of degeneration.

After operations for suture of divided nerves, and in most other cases of injuries to nerves, the chief need on the part of patient and surgeon is patience. After division of a nerve recovery is slow, especially if an interval has passed between division and reunion; reactions of normal quality are slow to reappear, particularly when there is a long stretch of nerve between the wound and the muscle tested. The most distal muscles suffer the most, and regain power and reactions the latest.

In the simplest cases of division followed by immediate successful suture a considerable time will elapse before any return of voluntary power can be recognized in the paralyzed muscles. Six months may be considered a short time to wait. In these favourable cases the sluggish contraction to cells will continue to be present, and to be fairly strong throughout. If an interval of time passes between the division of the nerve and the operation for suture, the reaction will probably have undergone some decrease in strength, and may even have almost disappeared at the time of the operation for suturing.

If this has happened, recovery will be very slow, and the appearance of a sluggish RD contraction may be the first change for the better in the electrical reactions. If the operation for suture does not heal without suppuration, the favourable result is apt to be much retarded.

Sherren tells us that in five cases of primary suture of the ulnar nerve at the wrist motion first returned to the paralyzed muscles, on an average, in 50 weeks after suture. In three patients the appearance of the hand became again normal in 12 months, 20 months, and 2 years after suture. In two instances of division of the nerve at the elbow, in one 100 weeks elapsed before voluntary power returned to the muscles of the hand; in the other the flexor carpi ulnaris regained voluntary power and reacted to the interrupted current 66 weeks after suture, but no recovery had taken place in the muscles of the hand 17 weeks later. After division of the median nerve at the wrist voluntary power returned to the paralyzed muscles on an average 40 weeks after suture.

The same authority found in his cases of suture for complete division that the return of irritability to interrupted currents coincided with the return of voluntary power, and says that in no case of suture of the nerves of the forearm which he had watched had voluntary power returned before irritability to interrupted current. On the other hand, he found that voluntary power returned first after incomplete injury.

In the following case voluntary power returned before visible reaction to interrupted currents: A patient, aged twenty-seven, had resection of the musculo-spiral nerve in May. In December there was visible voluntary movement of the extensors of the wrist, though not enough to move the wrist-joint. In the following February examination showed that there was fair voluntary power in the radial extensors of the wrist, but no reaction to interrupted currents. In April the radial extensors of the wrist were thought to show a faint flicker of response to the interrupted current, but no other extensor muscles showed any trace of reaction until a month later. Improvement continued, and the patient made a good recovery.

Among the practical points which continually arise in connection with the RD, perhaps none are more important than the giving of an answer to the question whether a nerve trunk is divided or only hurt. The question is one of the utmost importance, because the whole future conduct of the case rests upon the answer, and it may be difficult to answer it because RD will equally follow division and severe injury. Perhaps it will be useful to consider an actual case. A barber on board ship was at work with a pair of scissors, when the vessel gave a heavy roll,

and the patient accidentally plunged the scissors into his armpit. It bled a good deal, and was bandaged up tightly, and remained so for several days, until the ship came into port. He was then found to have extensive paralysis of the forearm and traumatic aneurism of the axilla. I was asked to report on the paralysis, and to state whether any nerves were divided or not. He showed RD in the ulnar and musculo-spiral areas. In the latter area one muscle, the triceps, did not show complete RD, for it retained its contractility to the coil in part, while in the ulnar area the paralysis was not absolute, the wasting was not extreme, and sensation, though impaired, was not altogether lost. On these grounds the report was given that the musculo-spiral nerve was not severed, and that in all probability the ulnar had also escaped. His nerve trunks accordingly were not explored, and under treatment by electricity he made a gradual but complete recovery. His paralysis probably had been caused by the tight bandaging and not by the punctured wound.

Another case was one of gunshot wound of the lower half of the arm with extensor paralysis. It was examined electrically about three weeks after the accident, when healing of the extensive lacerated wound had made good progress. There was RD of all the extensors, but wasting was not extreme, the contractions were of very good volume, and the sluggishness was not conspicuous. Judging that if the nerve had been completely severed the reaction of degeneration would have begun to enter the state of decreased irritability, and finding it to be not decreased, an opinion was given that the trunk of the musculo-spiral had escaped. The later history of the case proved this opinion to have been correct.

Much is hoped for from the testing with condenser discharges which has already been referred to in § 169, and is further treated in the next paragraph.

If this method should prove to become as valuable as it promises to be, the whole problem of the use of electrical testing in prognosis and in diagnosis may become transformed in character.

The testing of sensation provides better indications for prognosis than are given by the testing of the muscles. The beginning of a return of protopathic sensibility may be looked for after suture in about two months, and gradually protopathic stimuli

will become felt all over the previously anæsthetic area. Subsequently the return of sensation to a light touch will begin, and will slowly cover the area in the same way, and finally the power of discrimination of compass points and of accurate localization will return. No sensory recovery should be recorded as perfect unless the appreciation of the compass test is as good as on the sound side. After injury without division protopathic and epicritic sensibility return together, and the compass test soon afterwards.

223. **The Use of Condensers in Diagnosis.**—It would add very much to the utility of electrical testing if one could obtain trustworthy indications to mark out different degrees or grades of the reaction of degeneration. Indeed, one could go further, and say that, with the existing method of testing, many muscles are described as having normal reactions because they have not lost their power of response to interrupted currents, but in reality they are not normal in the true sense of the word.

By the use of a battery of condensers of different capacities it is possible to test a muscle with a series of current waves of gradually increasing length, and the capacity which gives the first visible contraction can be taken as the measure of the condition of the muscle. Thus, by using a series of twelve capacities, a scale numbered from one to twelve is provided, and it is found that, whereas a truly normal muscle reacts to the smallest capacity of the series, a damaged muscle requires a capacity which becomes progressively larger and larger in proportion to the amount of deviation from the normal which the muscle presents; muscles showing RD requiring relatively large capacities to provoke a contraction.

The use of condenser discharges for testing muscles has been advocated for a number of years by various investigators, but the work done by them has for the most part been more suited for the physiological laboratory than for the requirements of clinical medicine. Zanietowski has urged the application of the condenser method in clinical practice for a long time, but it is only quite lately that Cluzet* has described a practical apparatus adapted for everyday use, and he has given proofs of its real utility in diagnosis.

* "Avantages de l'emploi des décharges de Condensateurs dans l'Électrodiagnostic," *Paris Médical*, April, 1912. See also *Annales d'Électrobiologie*, May, 1910, August, 1910, for papers by the same author.

Several modifications of the condenser method have been proposed. In one the charging voltage is varied; in another, which has the merit of being simpler, a uniform voltage is used throughout, and this may conveniently be 100 volts, which can easily be taken from a direct current main supply by the method of a shunt resistance (§ 87). At 100 volts a suitable set of condensers would range from 0·01 microfarad to two microfarads, and the series may conveniently include ten intermediate capacities, making twelve steps in the scale. Muscles with the reaction of degeneration partial or complete require, at 100 volts, a capacity of 0·5 microfarad or upwards, in proportion to their degree of degeneration.

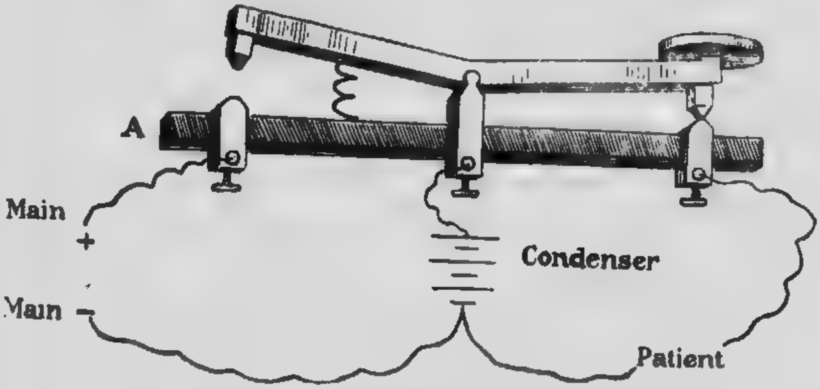


FIG. 163.—PLAN OF MORSE KEY FOR CHARGING AND DISCHARGING A CONDENSER.

The condensers are charged from the main, and discharged through the patient. This is effected by a key, which closes the two circuits alternately; the first closes the circuit between the source and the condenser, the second closes the circuit of condenser and patient. It is important that the first circuit be broken before the second is closed, for otherwise the full voltage of the charging source will reach the patient and cause a shock. The device employed is a "Morse key," and Fig. 163 shows its arrangement. On an ebonite base three contacts are fixed. The middle one carries a brass arm hinged at the centre to allow a seesaw movement, by means of which either extremity of the arm can touch its corresponding fixed contact on the ebonite base. The three contacts are joined up as shown in the figure, and it will be seen that one position of the hinged arm completes the

charging circuit from main to condenser, while the other position completes the discharging circuit from condenser to patient after breaking the circuit from the charging main. Such a mechanism can be adapted to the testing electrode shown in Fig. 51 by a slight modification of construction. Reference to the metronome (Fig. 56) shows that that also can be used as a Morse key, the three mercury cups taking the places of the brass contacts of Fig. 163. Finally, a revolving commutator worked by clock-work or by a small motor can be readily arranged to give the same cycle of events. When the condenser method of testing has been further developed by clinical use, it will supersede the method of testing which is now in vogue, and will enable electrical testing to provide additional information as to the condition of nerve and muscle in disease.

224. **The Myotonic Reaction.**—The ready production of duration tetanus (§ 167) is sometimes observed. It is connected with the reaction of degeneration, and may be confounded with it. The myotonic contraction is something analogous. It occurs in Thomsen's disease, and is characterized by a peculiar response of the muscles to electrical stimulation. These are thrown into prolonged tetanic contraction by interrupted and by continuous currents, and the state of contraction persists after cessation of the stimulus for a period lasting from five to thirty seconds, and then fades away gradually.

225. **The Myasthenic Reaction.**—A peculiar reaction is met with in the muscles of patients suffering from myasthenia gravis. The peculiarity consists in a rapid decrease in the amount of response shown by a myasthenic muscle when it is subjected to a series of stimuli. In other words, a myasthenic muscle shows the ordinary physiological effect of fatigue with abnormal rapidity.

This reaction is not constant in myasthenia gravis. Cohn has stated that even in the same patient it may be observed upon one occasion and not on another. He also states that the myasthenic reaction is provoked both by continuous and by interrupted currents. Other writers claim to have noticed a difference in this respect, and have observed the onset of the fatigue effect after interrupted currents only or after continuous currents only.

226. **The Reaction of Rich, and Other Reactions.**—Rich has described a variety of polar change in which the KOC contraction

appears readily. This is suspected in testing with moderate currents and using the kathode, if an opening contraction is produced in addition to the ordinary closing contraction. Rich considers that this reaction is peculiar to cases of compression of nerves, such as may occur after the use of Esmarch's bandage.

Capriati has observed a progressively increasing response to successive closures of a testing continuous current when the testing electrode was the kathode, and on reversing its polarity has seen a progressive decrease of the amount of response. On reversing again, the responses again grew stronger and stronger, and on reversal again grew weaker. He has suggested the name of the "antagonistic reaction" for this cycle of events. He has observed two cases, both times in muscles showing a reaction of degeneration.

227. **Treatment of Paralysis.**—Certain fundamental principles of treatment apply to nearly all cases of paralysis. In the first place the seat of disease is to be treated in the hope of setting up beneficial changes there, and in the second place the muscles are to be treated in order to exercise them and to stimulate their nutrition. Stimulation of the peripheral parts reacts upon the central organs through the medium of the sensory nerves, and thus acts favourably in a reflex manner. When the paralysis is purely motor, and the sensory functions of the affected parts are normal, this reflex mode of stimulation is of importance, and it follows that peripheral sensory excitation of a limb in infantile paralysis or in hemiplegia, or of the face in Bell's palsy, is a rational procedure.

Rhythmic stimulation is always to be preferred for the treatment of paralyzed or weak muscles, for the reasons already given in § 180. An arm or leg bath or a pair of electrodes placed one above and one below the affected area, as shown in Fig. 161, are the best means to adopt. The interrupted or sinusoidal current is to be used when the muscles respond to these currents, and the rhythmic continuous current when the muscles are in a state of RD and cannot respond to sinusoidal or faradic applications.

The duration of an application may be for from fifteen to thirty minutes or even longer. Bergonié, in considering the treatment of infantile paralysis, has even suggested treatments lasting for an hour, and repeated twice daily, and this serves to emphasize the general tendency of electrical treatment at the present time,

which is all in the direction of longer and stronger applications. The use of large electrodes and thick layers of moist material between the metal electrodes and the skin surface have rendered large currents not only tolerable but comfortable as compared with the imperfectly covered small button electrodes used formerly for treatment.

Where rhythmic interrupters are not available, one must be content with the old-fashioned handle and disc electrode, and this, the "active electrode," is to be moved in a gliding manner over the affected muscles. Care must be taken to use discs of at least 3 inches in diameter, and to have them thickly covered. The active electrode is made negative, and a solution of ammonium chloride or ammonium sulphate is more comfortable for the patient than sodium chloride, as the penetration of the ammonium ion at the negative pole causes less sensation than the sodium ion (§ 173).

In this procedure the gliding movements of the electrode serve to produce rhythmic variations of current through the different parts of the area traversed by the active electrode. The indifferent electrode is to consist of the usual metal plate, but should be thickly covered, and placed at or above the situation of the lesion causing the paralysis.

The chemical (ionic) effects of currents may also be utilized in the treatment of paralysis. An area of congestion in an injured nerve trunk, or the region where a nerve has been sutured after division, are assisted to recover by the molecular interchanges which can be set up in them by steady continuous currents.

For instance, in the treatment of facial paralysis, one should not be content with a stimulation of the paralyzed muscles. Ionic applications to the region round the point of exit of the nerve exercise a curative effect upon the seat of the paralysis in the facial nerve trunk, and do much to promote a quicker recovery.

It is perhaps hardly necessary to debate the question whether electrical treatment is of use in the treatment of paralysis. But if there are any persons who still dispute the efficacy of electricity, and try to maintain the proposition that the recovery from paralysis is due solely to natural causes and is quite independent of any electricity which may be used during the course of recovery, the following case may be quoted :

A gentleman, by sitting for a long time in one position in an armchair, compressed the musculo-spiral nerve, and numbness and weakness of the hand, with wrist-drop, was produced. There was no treatment for several weeks, and there was no improvement. When seen he had paralysis with partial RD in all the extensors of the wrist and fingers ; the supinator longus was also paralyzed, and there was impaired sensation over the back of the forearm and hand. The nerve trunk was tender to pressure at a point about halfway up the humerus.

Electrical treatment was commenced, and at the end of a fortnight the patient had gained considerably in voluntary power, and appeared to be on the highroad to recovery. Electrical treatment was therefore suspended. He was instructed to rub the limb daily and to exercise the muscles, and was told that he might expect the process of recovery to continue, even without further electrical treatment. A fortnight later he wrote saying that he had made no progress since the last electrical application. These were accordingly resumed, and improvement again began, and in another fortnight the patient was completely well.

The following instance of an Erb's paralysis is also instructive : A man fell into a ship's hold in January, 1898, and paralyzed the muscles of the upper arm. In the following year, March, 1899, he applied for relief, was seen and tested. A rupture of the fifth and sixth cervical cords of the brachial plexus was diagnosed, and an operation was performed for reunion. After the operation he disappeared from view for a time, and did not return until November. There was no recovery of power. The limb hung helpless from his shoulder. He was then tested electrically, and the examination showed a faint reaction of degeneration in the deltoid, biceps, and supinator longus. In the previous March. when tested before the operation, there were no reactions at all in these muscles. It was judged from the return of these faint reactions (RD) that reunion must have taken place after the operation, and electrical treatment was accordingly commenced. Improvement began immediately. After three months he had gained enough to be able to use the limb for light work, and recovery went on steadily afterwards.

For those who are not unwilling to be convinced, these cases seem to offer satisfactory evidence that the electrical treatment

played an important part in "curing" the paralysis, and answer the objection mentioned above, an objection which is not always easy to meet, because for obvious reasons it is difficult to combat it by direct proof.

All those who have had practical experience in the matter have seen cases of nerve injury begin to recover rapidly under electricity, after having been stationary for long periods of time under "expectant" treatment.

The cases of paralysis which follow injury to the nerve trunks are common, and are of interest from the exercise in applied anatomy which their diagnosis affords. The shoulder and upper limb are their most frequent seat. The chief causes of injury are contusions and lacerations, compression produced in various ways, and wounds with sharp instruments. Falls or blows upon the shoulder and dislocations of the shoulder-joint commonly produce paralysis of the muscles of that region. Pressure, as from the use of crutches, or from the weight of the body upon the arm during sleep, often produces paralysis of the muscles supplied by the musculo-spiral nerve, and incised wounds of the forearm and wrist often lead to paralysis of the muscles supplied by the ulnar and median nerves. In all cases of this kind favourable results may be expected unless the nerve trunks have been actually severed, or are involved in cicatricial tissue. In that case surgical measures to unite the ends of the divided nerve, or to relieve it from its surroundings, are necessary before recovery can be expected.

From what has been said in § 220 it follows that injuries of nerves are likely to be followed by a reaction of degeneration in the muscles which they supply, and this does always follow if the injury to the nerve has been sufficiently severe. But as such injuries may be of any degree of severity, it will be found that the reaction of degeneration is not invariably produced, for in the slighter cases the injury may be sufficient to impair motor and sensory conduction for a time without interfering with what may be called the trophic conduction of the nerve trunk. The partial reaction of degeneration is not uncommon in cases of nerve-trunk injury.

228. **Applications of Electrical Treatment.**—It is a matter of importance that all but the simplest forms of electrical treatment should be carried out by the medical man himself wherever this is possible, and if it is not possible for him to do so, then at

least he should supervise the treatment as often as he can. When the expense of electrical treatment applied daily for long periods by a medical man may prevent a patient from giving the treatment a fair and prolonged trial, it may be desirable to teach the patient or a relative or a nurse what to do. This is particularly the case in chronic conditions, where the necessary manipulations are simple, and where a successful result from the electrical treatment cannot be predicted with certainty. The aid of electro-therapeutic methods is often invoked only when every other treatment has been tried without success, and thus it happens that many cases have already become chronic and difficult to influence before they come for electrical treatment. Moreover, the mode of action of electricity upon the tissues of the body is in its essence a gradual one, working as it does by a slow rebuilding or regeneration of the damaged organ or function, and requiring time and the exercise of patience and perseverance in its applications. It is among the poor in hospital practice that one has the best opportunities of seeing the good which can be done by electrical treatment in chronic cases. In that class of patient considerations of expense do not interfere to cut short the treatment prematurely, nor are hospital patients so ready to throw up one kind of treatment in order to try something different. Thus it is a not uncommon experience to have similar cases under treatment at the same time, the one at the hospital and the other as a private patient, and to see the latter throw up the treatment when half through with it, while the former goes steadily on and makes a good recovery.

Whenever the treatment must be carried out by a nurse, the most suitable apparatus for her use must be properly chosen by the medical man, and she should be properly instructed in its use, and should be given a few lessons in the anatomy of the part to be treated, and in the manipulations to be performed. She must be supervised at frequent intervals by the medical man in charge of the patient, who should never omit to make measurements and tests from time to time to ascertain what progress is being made, and to prevent the case from being left in the sole charge of the nurse.

229. **The Ocular Muscles.**—Their deep-seated position, the proximity of the retina, and the sensitiveness of the conjunctiva, all help to make it practically impossible to excite contractions

in these muscles by electrical applications, except in the levator palpebræ, in which a "longitudinal" reaction of degeneration has been observed. Good results have sometimes appeared to follow treatment by means of direct currents applied longitudinally through the skull, the kathode being placed upon the closed eyelid. Buzzard has recommended the use of the operator's index finger as the active electrode. Small sponges may also be used, as they are soft and readily adapt themselves to the surface of the eyelid. Owing to the difficulties of satisfactory application, electricity is not much used in the treatment of ocular paralyses.

230. **The Fifth Nerve.**—The muscles supplied by this nerve are the masseter, temporal, and pterygoids. When these are paralyzed the jaw is deflected to the paralyzed side by the action of the external pterygoid of the sound side. It is not at all common to see these muscles affected, though occasionally a case may be met with, and a reaction of degeneration may be observed.

231. **Facial Paralysis.**—This form of paralysis very frequently comes under electrical treatment.

Paralysis of the facial muscles may be the result of cerebral disease, as in hemiplegia, cerebral tumour or meningitis, but its most common cause is disease of the nerve trunk itself. The part of the nerve which is usually at fault is that which passes along the Fallopian aqueduct. In this part of its course a slight amount of swelling of the sheath of the nerve, or of the lining of the bony canal, is sufficient to produce compression of the nerve fibres, and consequently a paralysis of the facial muscles. This is the generally accepted explanation of the fact that facial paralysis is frequently seen in persons who are otherwise in good health. In many of these cases the onset of the paralysis can be attributed to some definite exposure to cold, and especially to a cold draught of air blowing upon the cheek, but in many others the history is by no means conclusive in this respect. A "rheumatic" tendency has been assumed as a predisposing cause. The common occurrence of facial paralysis is probably associated with this anatomical peculiarity of its course through a narrow bony canal, as any compression produced by congestion at that part of its course is likely, when once started, to lead to strangulation and greater congestion.

As the severity of the paralysis in these cases will depend upon the length of time during which the nerve fibres are com-

pressed, it is very important to endeavour to reduce congestion as early as possible. The application of blisters or leeches should always be attended to in cases of facial paralysis if they are seen soon after the onset, or an ionic application with salicylic ions may be made as soon as the case comes under observation.

Facial paralysis is often associated with disease of the ear, and is then due to an extension of the inflammatory process to the Fallopian canal, or to the facial nerve itself. It is also injured sometimes in operations on the middle ear. It may also be caused at birth by pressure of the obstetrical forceps upon the nerve after its emergence from the skull.

The reaction of degeneration, complete or partial, is present in a large proportion of cases of facial paralysis. Normal reactions may remain in mild cases. Sometimes it happens that the reactions of the upper part of the face may differ from those in the lower part, showing an unequal degree of damage to the respective groups of nerve fibres. If the patient is tested daily from the commencement, the gradual development of the RD will be clearly seen. As the reaction to the induction coil current may not disappear until the lapse of seven or ten days from the time of onset, a favourable prognosis cannot safely be given from a test made within that time. In testing a case of facial paralysis, it is well to bear in mind that the skin of the face is sensitive, and that the muscles are near the surface ; strong currents are therefore unnecessary, and must be avoided. Usually the uncomplicated cases make a good recovery, and improvement may go on slowly for a year or more. Old patients do not usually recover so well as younger people. A considerable proportion of cases of facial paralysis occurs in young women ; they are excellent examples for study, as they attend with the greatest diligence until completely recovered.

If a case of simple facial paralysis receives no electrical treatment, its rate of recovery will be slower than if it be so treated. The cases of facial paralysis from ear or bone disease are naturally more unfavourable than those coming on from "cold." The hemiplegic cases usually recover fairly without treatment Care must be taken to exclude all likelihood of the existence of unfavourable causes of the paralysis before making a favourable prognosis. All cases presenting unusual features are to be regarded with suspicion. Facial paralysis from disease of the motor nucleus of the nerve may occur.

The electrical treatment should be in accordance with what has been laid down for paralysis in general—viz., direct treatment of the affected nerve and muscles, and ionic applications to the trunk of the nerve by means of an electrode applied around the under side and front of the ear. For cases showing the reaction of degeneration both the direct and the interrupted current should be used. The indifferent positive electrode should be placed at the back of the neck, and the active electrode applied to the nerve and the muscles, each of the main branches of the nerve being followed along gradually from centre to periphery, and each muscle being treated with a few interruptions with the help of the closing key. Lastly, the skin of the face and the muscles may be treated with the induction coil. If normal reactions have not been lost, treatment with induction coil currents will be all that is required. A metal-mounted brush of bristles can be converted into an electrode, and makes a good instrument for applications to the face. A large electrode adapted to the whole side of the face may be used with a rhythmic interrupter.

It has been proposed by Ballance and Stewart to remedy the deformity produced by permanent facial paralysis by an operation to connect the peripheral part of the facial nerve to a strand taken from the hypoglossal or spinal accessory.*

A "secondary contraction" of the facial muscles is often seen in cases of facial paralysis. Usually it shows itself during the course of recovery in the more serious cases. There may be a tonic contraction which shows itself in a narrowing of the palpebral opening on the affected side, or in a drawing of the angle of the mouth to the affected side, or there may be occasional twitchings in some of the affected muscles. Again, there may be an associated action of the muscles, so that movements of the eyelids occur when the muscles of the lips are set in action, and, conversely, the mouth may move when the eyes are closed. This secondary contraction in the muscles of the face has nothing in common with the "late rigidity" which appears in the limbs in cases of hemiplegia. It is the result of the remains of the original mischief which has caused the facial paralysis in the first instance, for the presence of a certain degree of thickening around the nerve trunk may act as a source of irri-

* *British Medical Journal*, May 2, 1903.

tation to the nerve, and thus cause the tendency to spasm. Ionization with chlorine ions is indicated.

232. **The Tongue and Soft Palate.**—Injury or disease of the hypoglossal nerve may cause paralysis of the muscles of the tongue. Atrophy of one side of the tongue and a reaction of degeneration have been observed, and may be recovered from. The soft palate is occasionally paralyzed, and its muscles may show a reaction of degeneration. If it should be required to test any of these muscles, a small electrode should be used; it may be covered by a layer of moist absorbent cotton, or it may be used uncovered.

233. **The Trapezius and Sterno-mastoid.**—Paralysis and atrophy of these muscles follow injury or disease of the spinal accessory nerve, or of its nucleus. The trapezius, and sometimes the sterno-mastoid muscle as well, may suffer as a result of the suppuration of strumous glands in the neck, or of the surgical operations for their removal, also in some cases of anterior poliomyelitis and in some forms of progressive muscular atrophy.

Paralysis of the sterno-mastoid is easily recognized if looked for. When the head is turned towards the opposite side, the outline of the muscle standing out under the skin is plain to see in health, but is lost if the muscle is paralyzed.

When the trapezius is paralyzed there is a general feeling of weakness, and a complaint of myalgic pains about the shoulder, because the muscle plays so large a part in supporting the shoulder during the movements of the upper limb.

When one trapezius is paralyzed the difference between the two shoulders can easily be recognized, particularly if the muscle be wasted as well. On the affected side the whole of the shoulder is lowered, and the line from the neck to the shoulder-tip is flattened. This difference is best seen with the arms hanging at the sides (Fig. 164). The position of the scapula is changed and the inner border of the bone does not lie parallel to the vertebral column, as in health, but at an angle with it, its upper corner being rather further from the middle line, and its lower angle nearer, at a higher level, and more prominent. Duchenne has explained why this is the case. The shoulder, having lost the support of the upper part of the trapezius, hangs suspended from the levator anguli scapulæ, and turning as on a pivot, at the point of attachment of that muscle, its lower angle is tilted

inwards and upwards, and the acromion sinks downwards by the weight of the arm.

If the patient raises the arms to the head another peculiar defect comes into notice—namely, that the clavicle in its outer half comes into view from behind. This is a valuable diagnostic sign of atrophy of the muscle (Fig. 165). The rhomboids can also be plainly seen when the trapezius is wasted.

Paralysis of the trapezius is often due to injury of the spinal accessory nerve during surgical operations on the neck. In one

Fig. 164.—Paralysis of Left Trapezius.

such case the incision was a small one, at the posterior border of the upper part of the sterno-mastoid. The nerve was accidentally divided, and the muscle became wasted, especially in its upper and middle portions. The clavicular part—the *ultimum moriens* of Duchenne—as well as the rest of the muscle, showed a marked reaction of degeneration. The lower part of the muscle was not quite so much affected as the upper part, and the inferior angle of the scapula was therefore pulled downwards and not tilted upwards, as is the case when the whole muscle is paralyzed. The lower part of the trapezius is supplied by branches of the third and fourth cervical nerves, and these may escape when the spinal accessory is injured, and the lower sur-

viving part of the trapezius pulls the scapula downwards. In another case the whole of the side of the neck was much scarred, as the result of numerous strumous abscesses and of the surgical treatment for their relief. Both the trapezius and sterno-mastoid on the right side were extremely wasted.

The results of treatment in cases of paralysis of the sterno-mastoid and trapezius will depend upon the nature of the nerve injury. Where the nerve has been divided and scar tissue is left surrounding the divided parts, the chances of a spontaneous

FIG 165.—PARALYSIS OF LEFT TRAPEZIUS.
Clavicle seen from behind.

reunion of the nerve are very small, and a surgical operation for the restoration of continuity in the divided nerve should be tried.

Recovery has gradually appeared in some cases where there has been reason to believe that the nerve was divided, and in such cases it is probably due to spontaneous regeneration of the nerve at its divided part. The levator anguli scapulæ assumes some of the functions of the lost trapezius, and becomes increased in size. Electrical treatment should be energetically applied if there are reasons for hoping that the nerve is not completely divided, or if there are signs of returning power.

The condition known as Sprengel's deformity, or congenital elevation of the scapula, simulates a spasm of the trapezius. See § 264 for a description and figure.

234. **The Serratus Magnus.**—Paralysis of this muscle is interesting, because the deformity which results from it is peculiar. The serratus magnus is supplied by the posterior thoracic nerve, which rises from the fifth, sixth, and seventh cervical cords, and runs down the side of the chest behind the brachial plexus to reach the muscle. In the first part of its course the nerve runs in the substance of the scalenus medius muscle. The position of the nerve makes it liable to injury, especially in the side of the neck, and its independent course may explain the reason why paralysis of the serratus magnus is frequently seen without any other muscle being affected at the same time. Occasionally the nerve to the rhomboids comes off as a branch from the first part of the nerve to the serratus, and therefore the rhomboids may be paralyzed with the serratus magnus.

The peculiar deformity which characterizes paralysis of the serratus magnus is easily recognized if looked for. When the patient is examined with the arms hanging down, the shoulder may seem natural, but when the patient attempts to extend the arms horizontally in front of him the movement is performed imperfectly, and the posterior border of the scapula on the affected side becomes prominent, projecting like a ridge from the level of the back (Fig. 166). In a healthy person the scapula remains applied to the thorax during this movement; the function of the serratus magnus is to hold the scapula closely to the side of the thorax, and to advance it towards the front. When the arms are extended in front, the action of the deltoid tends at the same time to throw the scapula backwards, and this is resisted by the simultaneous contraction of the serratus magnus. If the deltoid be paralyzed as well as the serratus, the patient cannot extend his arm horizontally, and the deformity due to the paralysis of the serratus cannot be brought out in the way just mentioned. In this case, if the shoulder be pushed back while the patient is told to resist, it may be found that the posterior border of the scapula can be more easily displaced on the side of the paralysis.

Paralysis of the serratus magnus is not uncommon as a result of direct injury to the nerve in the side of the neck. The following example will serve as an illustration of the usual

history of such cases: A man was using an iron bar as a lever to move heavy weights along the ground, which he did by putting the end of the bar on his shoulder, and pushing upwards forcibly against it; he felt a pain, and soon afterwards he found that his shoulder began to "grow out." When he came under observation there was marked paralysis of the right serratus magnus, and the rhomboids were also affected, which made the characteristic deformity of the shoulder even more pronounced.

Paralysis of the serratus magnus may occur as part of an extensive injury to the region of the shoulder. In two cases of

FIG. 166.—PARALYSIS OF RIGHT SERRATUS MAGNUS.

which I have notes the patients had suffered severe injuries, one having been crushed in a lift accident, in which he broke his forearm, and the other having been hurt by a heavy packing-case, which fell upon him. Both of these, in addition to other injuries, had paralysis of one serratus magnus—the right.

Paralysis of the serratus magnus is fairly common as a result of neuritis, quite apart from injury. I have seen cases after most of the specific fevers, several after influenza and after pregnancy, and one in which it came on after an illness, presumably of a septic nature, which followed the passage of a catheter. An instance in which this form of paralysis followed

small-pox is described and well figured in the *Journal of the Royal Army Medical Corps*, April, 1904.

Cases due to injury or disease respond well to electrical treatment, unless the nerve is actually divided ; division of the nerve is not often met with.

In testing and treatment the indifferent electrode is placed in the posterior triangle of the neck, and the active electrode is applied to the serrations of the muscle. The patient should lie down with the arm raised and the hand behind the head.

The notion is sometimes entertained that the peculiar position of the shoulder-blade, described above, is due to dislocation of the latissimus dorsi from its position at the angle of the scapula. This view is erroneous. Sherren states that the winged scapula is most marked when there is a simultaneous affection of serratus and of lower trapezius, the latter due to injury of the cervical branches, occurring with the injury to the long thoracic nerve.

235. **The Scapular Muscles.**—The supra- and infra-spinati are often paralyzed as the result of blows upon the shoulder, though less frequently than the deltoid.

When the spinati are wasted, the spine of the scapula becomes prominent, and the muscles themselves can be seen to be diminished in bulk. The patient is unable to perform external rotation of the humerus in a proper manner if the infra-spinatus is paralyzed, and the other external rotator of the humerus, the teres minor, is often affected simultaneously, though supplied by a different nerve. The movement of external rotation is necessary in writing for moving the hand across the paper, and in sewing the same muscles also come into play.

The nerve (supra-scapular nerve) which supplies the spinati is exposed to the risk of injury, owing to its superficial position on the shoulder. In one case I have seen it injured by the carrying of a ladder upon the shoulder. The supra-spinatus is a less important muscle than the infra-spinatus, and its condition is not so easy to determine, because it is thickly covered by the trapezius, which makes electrical testing of the muscle difficult, and its functions as an elevator and a weak internal rotator of the humerus can be performed by the deltoid. When the infra-spinatus is paralyzed it is probable that the supra-spinatus is in the same condition.

The internal rotators of the humerus—namely, the subscapu-

laris and teres major—have a nerve supply (the subscapular nerves), which escapes injury much more often than the spinati; and the same may be said of the latissimus dorsi, which is also supplied by a branch from the brachial plexus—viz., the long subscapular. The pectoralis major and minor also escape, as a rule.

There is no special point to note in the electrical testing and treatment of these muscles, which should follow the methods already prescribed for the treatment of paralysis. Usually they are affected with the deltoid, and their treatment is similar to that which is employed for the latter.

236. **The Deltoid.**—Paralysis of this muscle from blows upon the shoulder or dislocation of the shoulder-joint is one of the most common forms of paralysis in the upper extremity.

The circumflex nerve is exposed to injury in its course through the muscle, and its trunk may also be strained in dislocations, or it may be compressed by a crutch or axillary pad. The teres minor suffers with the deltoid when the injury is to the trunk of the nerve; when the injury is in the intra-muscular part it may escape. It is not always easy to determine the state of the teres minor by electrical testing, as it is so much covered by other muscles, nor by observing the voluntary movements of the patient, as its functions can be adequately performed by the infra-spinatus. The attempt to ascertain its condition, however, should always be made.

The spinati are often paralyzed by the injury which paralyzes the deltoid.

The flattened appearance of the shoulder and the prominence of the acromial process of the scapula make it easy to recognise paralysis of the deltoid unless the subject be very stout. In infants especially the adipose tissue which covers the shoulder may mask the wasting of the muscle. When the wasting and paralysis are extreme the head of the humerus is no longer held up in the glenoid cavity, but can be seen and felt to hang loosely in a state of partial dislocation, and to be freely movable in its socket. One may even be able to push the tip of a finger between the acromion and the head of the humerus.

When the deltoid is paralyzed the arm cannot be raised to the horizontal position, and the utility of the limb is very seriously diminished for a very large number of movements, as no other muscle is able to supplement its action to any appreciable extent. The supra-spinatus, which has a similar function, is too

feeble to be able to raise the weight of the arm. On one occasion I have seen a patient able to hold out the arm horizontally although the deltoid was completely paralyzed. It sometimes happens that part only of the deltoid is paralyzed; I have notes of three cases. In one the patient had had suppuration round the shoulder, and an incision for the evacuation of the pus was made on the posterior aspect of the joint. One of the branches of the circumflex nerve was injured, and the posterior half of the muscle was wasted, and showed a partial reaction of degeneration, while the anterior part reacted naturally.

Traumatic paralysis of the deltoid is very common. Recovery is the rule in the majority of cases, but there is a considerable minority which do not improve at all satisfactorily, and on this account it is wise to express a guarded opinion when there is much wasting and a reaction of degeneration, and the prognosis must be made to depend upon the behaviour of the muscle under treatment. In elderly people particularly the progress of recovery is very slow, and six months or more may pass before much improvement is visible. If the electrical reactions are normal, or show only a quantitative change, or show the partial reaction of degeneration, with some preservation of induction-coil reactions, the prognosis is more favourable. Taken generally, the deltoid may be said to be a muscle which is easily damaged, and has not a very great recuperative power. The presence of articular changes in a case of paralysis of the deltoid is very common, as both muscle and joint are supplied by the circumflex nerve, and both suffer when the nerve is injured. Adhesions in the joint should be treated by mechanical means after the nerve has recovered its functions. If the adhesions are broken down before the muscle and nerve are restored they are very likely to form afresh. The skin over the deltoid receives sensory fibres from the circumflex nerve, and loss or impairment of sensation is frequently to be found if looked for when the muscle is paralyzed.

237. **The Musculo-spiral Nerve.**—Paralysis of the muscles supplied by this nerve is characterized by the presence of wrist-drop. Usually the extensors of the wrist and fingers and the supinator longus and brevis are involved; the triceps may either escape or may be implicated, according as the injury is high up in the arm or not.

Musculo-spiral paralysis from pressure on the trunk of the nerve during sleep is extremely common—at least, among hospital patients.

The usual history is that the patient goes off into a heavy sleep, from which he awakes with his hand and forearm powerless. Often the patient has slept while sitting at a table with the head resting on the arm, or with the arm hanging over the back of a chair; in either case the musculo-spiral nerve trunk has been pressed upon. It does not often follow sleep in bed. Almost always the patient has been under the influence of alcohol and has slept very soundly. Otherwise the discomfort felt in the arm would have been likely to awaken him before the production of more than a transient paralysis. Nearly all the cases are in intemperate persons. The predisposing effect of intemperance is well shown in the following case: A potman, after sleeping two or three hours, developed a pressure palsy of his left musculo-spiral nerve. This got better, but in the following year he injured his ankle, and was obliged to use a crutch. This brought on another attack of musculo-spiral palsy before he had used the crutch more than ten days.

Slight degrees of temporary paralysis from pressure on a nerve-trunk during sleep are familiar to most persons. To notice a numbness or a feeling of pins and needles in one arm on awakening from sleep is not uncommon, especially among those who are in a poor state of health.

Pressure paralysis has been thought to be secondary to compression of the bloodvessels of the limb, producing anæmia of the nerve; but if this were the case the paralysis should not be confined to the region of one particular nerve trunk, as is the rule if it were due simply to anæmia of the limb from compression of the main artery. It would rather be expected to involve chiefly the distal parts, irrespective of the nerve supply.

A case of a pressure palsy in the leg, which came under my observation some years ago, shows that it is the nerve itself which suffers from compression. In that case the pressure was on the great sciatic nerve at the back of the thigh, and there could not have been any compression of the femoral artery. The patient was a young man who attended a meeting, and in order to have a better view of the proceedings, he sat for an hour upon the back rail of his chair; at the close of the meeting he found his leg numb and helpless, and was assisted home.

Two days later he came under observation. He had paralysis of all the muscles below the knee. He recovered in a fortnight under treatment by rubbing and the induction-coil current.

Sleep palsies are almost always limited to the musculo-spiral nerve.

In crutch palsy, too, it is usually the musculo-spiral nerve alone which is paralyzed, but the circumflex or the ulnar nerve or median may also be involved. Sleep palsies are always unilateral; crutch palsies may be double if two crutches are used; they are usually more marked on the side of the injured leg.

The degree of impairment of sensation varies much; as a rule, there is some complaint of numbness on the back of the forearm and hand, and some anæsthesia may be detected.

Paralysis of the extensor group from lead-poisoning is frequently met with. Fractures of the humerus may cause extensor paralysis from injury to the trunk of the musculo-spiral nerve by the broken bone, or the nerve may be implicated in the callus thrown out around the fractured points.

A rare form of extensor paralysis is one which affects the special extensors of the thumb. I have twice seen a paralysis of these muscles alone with a reaction of degeneration in cases without any history of previous injury.

All these forms of extensor paralysis vary considerably in severity. Those in which the electrical reactions are not much impaired may recover in ten days or a fortnight. When the reaction of degeneration is present the duration will be longer, and may last for more than three months. Recovery can be confidently expected in uncomplicated cases, where the pressure has not lasted very long, and it is certainly promoted by electrical treatment. I have often seen improvement start at once on the commencement of electrical treatment, after weeks had been wasted in vain in the expectation of spontaneous recovery. It is probable, however, that even in these the paralysis would go away of itself in time, but this does not prove that electrical treatment is unnecessary.

When the pressure is due to the use of crutches they must either be given up, or, if that is impossible, the head of the crutch must be well padded, and the state of affairs must be explained to the patient, so that he may be able to co-operate. Crutches with handles which can be grasped in the hands are the best, for with them the patient can transfer part of his weight

from the armpits to the wrists. The crutches should be attended to before they have produced paralysis.

238. **The Ulnar and Median Nerves.**—These nerves are frequently divided at or near the wrist by incised wounds, a very large number of the cases being from cuts caused by broken glass. It is not uncommon for both nerves to be divided in one accident, and if the ends are not reunited when the wound is first dressed, wasting and paralysis of all the intrinsic muscles of the hand is the result. The nerve may also be injured at the elbow, and cases have been recorded in which a fracture of the internal condyle of the humerus has been followed some years afterwards by interference with the function of the ulnar nerve.

When the ulnar nerve has been completely divided near the wrist the symptoms produced are: Paralysis, with wasting and the reaction of degeneration in the hypothenar eminence, in all the interossei, in the two ulnar lumbricales, and in the adductor and flexor brevis (inner head) of the thumb. After a time the deformity known as the "clawed hand" is produced. The palm becomes thin and flat, the heads of the metacarpal bones and the flexor tendons in the palm become unduly prominent, the proximal phalanges are over-extended, the distal phalanges are permanently flexed. This is the result of the paralysis of the interossei. These muscles flex the proximal phalanges and extend the distal ones, and so balance the movements of the fingers, which are performed by the long flexors and extensors. If the interossei are paralyzed, the unbalanced action of the long extensors and long flexors produce the characteristic deformity.

The ulnar nerve supplies with sensibility to light touch one and a half fingers, and the corresponding portion of the palm and dorsum of the hand. It supplies with sensibility to prick exclusively or with other nerves, the little and ring fingers, the palm, with the exception of the thenar eminence, and on the dorsum that portion of the hand to the ulnar side of a line drawn through the axis of the middle finger. In division of the nerve, sensibility to light touch is lost over both surfaces of the little and half the ring fingers, with a corresponding portion of the palm and dorsum of the hand. This area is liable to very little variation. An area insensitive to prick is present over the little finger back and front, and a portion of the ulnar palm

varying from a strip on its extreme border to an area almost as extensive as that of the loss of light touch (Sherren).

After division of the median nerve at the wrist the conditions are different; the clawed hand, which is so characteristic of the divided ulnar nerve, is not present, and the chief feature is the wasting of the thenar eminence and the everted or ape-like thumb, which lies with the nail facing dorsally; the abductor, opponens, and outer head of the flexor brevis of the thumb are paralyzed, atrophied, and show the reaction of degeneration.

Sherren, in summing up the sensory supply of the median nerve, states that it supplies sensibility to prick, partly exclusively and partly in common with other nerves, to the whole of the palm, with the exception of a narrow strip along its ulnar border. On the dorsum it supplies the whole of the dorsal surface of the index, middle fingers, and in most cases the ring finger and the terminal phalanx of the thumb. If, as often happens in many of the injuries in the neighbourhood of the wrist, tendons are divided in addition to the nerve, this usually results in the appearance of an area insensitive to deep touch almost as extensive as that of loss of sensibility to prick.

The ulnar nerve may be injured in the palm, and in this case the hypothenar muscles and one or more of the interossei may escape, while the others show a reaction of degeneration.

239. **Combined Paralyses of the Upper Limb.**—It may happen that muscles supplied by more than one nerve trunk may be paralyzed together from injury or disease. This is often the case with the ulnar and median nerves. After dislocation of the shoulder, and particularly when a dislocation has remained for some time unreduced, there may be complete paralysis of the whole limb.

Several causes combine to produce extensive paralysis after a dislocation. In dislocations forward the head of the humerus presses upon the brachial plexus below the coracoid process, and so produces paralysis below that point, but this pressure will not cause paralysis of the muscles of the scapula, for these are supplied by branches given off higher up, and yet they are generally, if not always, implicated. It is said that the upper cords of the plexus may be compressed between the clavicle and the vertebral column if the violence has tended to drive the shoulder backwards, but this is doubtful. The upper cords of the plexus may be directly subjected to traction from the

injury, or finally they may be damaged by the efforts employed in reducing the dislocation.

It seems probable that the commonest cause of injury to the upper cords of the plexus is a stretching force acting usually at the time of the injury or possibly in the efforts to reduce the dislocation, while the muscles of the forearm and hand are paralyzed subsequently from the pressure of the dislocated head of the bone upon the lower cords. Severe injury to the shoulder may cause rupture of the nerve roots which form the brachial plexus. When the spinal nerve roots are torn there may be laceration of the fibres which emerge from the thoracic cord to supply the cervical sympathetic, and the pupil on the injured side may be contracted in consequence. Bowlby * has published some cases in which this has been observed, and Sherren † has recorded a case with an illustration.

240. **Post-anæsthetic Paralysis.**—Paralysis of some of the muscles of the upper limb has been observed after an operation under an anæsthetic, particularly when the operation has been prolonged. Usually this is due to some faulty attitude of the patient or of the limb, which has led to compression of a nerve trunk, and has been overlooked. Generally the paralysis is of the muscles supplied by the musculo-spiral nerve, or it may be an Erb's paralysis (§ 242). The anæsthetist is sometimes blamed. Without entering into the question whether the anæsthetist is to be held responsible for the prevention of pressure palsies during operations, the following case may be related: During an operation the anæsthetist noticed that the surgeon seemed to be leaning heavily against the patient's arm, which hung down from the table. He mentioned it, and the limb was examined, and a mark of pressure could be seen. The faulty position was corrected, but nevertheless a paralysis of the musculo-spiral resulted, with a reaction of degeneration in the muscles. Thus it is probable that a very short period of compression may suffice to cause a serious paralysis.

241. **Volkmann's Ischæmic Contracture.**—Paralysis from the pressure of splints and bandages is sufficiently common to be of importance, and though, fortunately, it is not usual for injury produced in this way to cause permanent harm, yet sometimes it does so. I have notes of many cases in which there was little

* "Injuries and Diseases of Nerves," J. and A. Churchill, 1889.

† "Injuries of Nerves and their Treatment," J. Nisbet, 1908.

or no doubt that tight bandaging had caused paralysis. Thus in one patient who received an incised wound involving the median and ulnar trunks, it was found, when the wound had healed, that he had developed a paralysis of the musculo-spiral as well. Paralysis from tight bandaging is seen with especial frequency among persons who have received injuries when far away from skilled assistance, and have had their injuries bound up tightly and left so until medical assistance could be reached. But it is by no means limited to such cases. There is a very serious condition known as Volkmann's ischæmic contraction which is seen in connection with tight bandaging, and most frequently in children after fracture of the forearm. It is characterized by the rapid development of contraction of some of the muscles. Most commonly it is the flexor group in the forearm. The muscles become shortened, hard, and inelastic; reactions are difficult to obtain, particularly at first, but they may be normal. The condition is attributed to strangulation of the blood-supply to the muscles, with consequent interstitial œdema and myositis, leading to the formation of fibrous tissue. The injury is permanent. The pressure which produces the muscular damage may, and often does, produce injury to nerves as well, but the two things appear to be separate, for the contractured muscles do not necessarily show the reaction of degeneration, but rather show a normal response of poor quality, while neighbouring muscles not in a state of contracture may show flaccid paralysis, with a reaction of degeneration.

Thus Wilfrid Harris* has recorded nine cases, in seven of which there was paralysis and a reaction of degeneration in the intrinsics of the hand, in the flexors of the wrist and fingers, or in all the muscles of the forearm and hand.

Although most of the recorded cases of Volkmann's contracture have occurred in children after fracture of the forearm, the condition may follow tight bandaging in other parts. Dudgeon,† who has recorded fifteen cases, mentions one following the application of an Esmarch bandage to the arm for seventy-five minutes. Greig‡ has seen a case of contracture of the leg muscles after bandaging for a fractured thigh. The calf muscles

* "Ischæmic Myositis and Neuritis," *British Medical Journal*, September 26, 1908.

† "Volkmann's Contraction," *Lancet*, January 11, 1902.

‡ *Edinburgh Medical Journal*, 1910.

were atrophied, hard, and contracted. In a severe case which came under my own care the compression was due to a few turns of bandage applied to the bend of the elbow after venesection. The patient slept very soundly, with the forearm flexed in such a way as to produce strangulation of the circulation below the elbow. Permanent contraction of the flexor muscles resulted. There was no reaction of degeneration.

242. **Root Paralyses—Erb's Paralysis.**—Paralysis of muscles caused by injury or disease of the cervical nerves which go to form the brachial plexus has been called "radicular paralysis" or "root paralysis." The grouping of the affected muscles in these cases will depend upon the representation of the muscles in the different spinal nerve roots which go to make up the brachial plexus (§ 211), and will not correspond with the grouping according to nerve-trunk distribution. It is evident that electrical testing may be of prime importance in distinguishing between paralysis due to nerve-trunk lesions and those caused by lesions of the nerve roots.

One particular type of root paralysis affecting the muscles of the shoulder and arm has received the name of Erb's paralysis, though in France it is often known as the Duchenne-Erb type, because Duchenne first drew attention to it in 1867, and reported five examples. It was Erb who, in 1874, pointed out the anatomical reasons for the special grouping of the paralyzed parts. Erb enumerates the affected muscles as the biceps, coraco-brachialis and brachialis anticus, which are supplied by the musculo-cutaneous nerve; the deltoid, supplied by the circumflex nerve; and one muscle supplied by the musculo-spiral, namely, the supinator longus; sometimes the spinati too (suprascapular nerve) are involved. The affection of the supinator longus alone among the muscles supplied by the musculo-spiral nerve might seem at first to be a perplexing feature, but it is easily explained on the ground that the injury is situated above the point at which the musculo-spiral nerve is built up. Compare the condition in wrist-drop from lead, in which the supinator longus may escape when the rest of the muscles supplied by the musculo-spiral nerve are paralyzed. Erb pointed out that an injury limited to the two upper roots of the branchial plexus, the fifth and sixth cervical, or their combined trunk, would produce the kind of paralysis under consideration; and further showed that these cords can be directly

stimulated at a point in the neck an inch above the clavicle and a little external to the outer border of the sterno-mastoid. This is known as Erb's motor-point, and by means of an electrode applied to it, the group of muscles in question can be readily thrown into simultaneous contraction.

The existence of Erb's paralysis as a clinical unit depends upon the comparatively exposed position of these two nerve roots, just as we have seen that paralysis of some of the single muscles of the shoulder are common for the same reason, and varieties in the extent of the paralysis exist according as the injury or disease affects chiefly the fifth or the sixth roots or their united trunk, or extends into the seventh.

From what is known one would expect that a lesion of the fifth and sixth roots, or of their combined trunk, should involve not only the muscles already mentioned, but also the rhomboids, the teres minor, the subclavius, and the upper parts of the pectoralis major and serratus magnus, and the supinator brevis, and most of these muscles have been noted as involved in some of the recorded cases. When they escape it must be due to their partial representation in one or more of the other nerve roots of the brachial plexus.*

It must be borne in mind that Erb's paralysis is not a special form of disease. The name signifies the paralysis of a special group of muscles. Any sort of injury or disease which affects this special part of the brachial plexus will produce paralysis of the group of shoulder and arm muscles already mentioned. Traction on the arm of a child during difficult labour is a common cause of Erb's paralysis, so that Duchenne described it as "obstetrical" palsy of the arm. Among twenty cases of which I have notes, seven were caused in this way, four followed direct injury, one was due to sarcoma of the cervical vertebræ; but in that case, from the extension of the disease, the paralysis was not long limited to the muscles of the Duchenne-Erb group. One was associated with an abscess in the neck, and the remainder came on gradually, and were due to neuritis.

All degrees of combined paralysis, from the typical Duchenne-Erb type to complete paralysis of the shoulder and arm, may be met with.

* For much important work upon these and associated matters, see Sherrington, "The Spinal Animal." Medico-Chirurgical Transactions, 1899.

The triceps in some cases and the extensors of the wrist in others have been noted to be weak in cases of Erb's paralysis. In two cases I have noted some weakness of the upper part of the pectoralis major.

Wilfred Harris and Warren Low* believe that the characteristic lesion of Erb's paralysis is situated in the fifth cervical root, and not in the common cord formed by the junction of the fifth and sixth, and they further state that they have found the pronator radii teres and the radial extensors of the wrist to be involved in association with the other muscles generally affected in Erb's group. Kennedy,† in a paper on the treatment of birth-palsies by operation and suture, states that in all his cases the lesion found was at the junction of the fifth and sixth nerves.

There is a certain amount of variation between individual cases, so that we cannot state absolutely that certain fibres run always in the fifth root, and certain others only in the sixth or seventh. Moreover, many or most of the limb muscles receive their nerve supply by roots emerging at more than one level; for example, the serratus magnus from the fifth, sixth, and seventh cervical roots.

Cases are met with occasionally in which the intermediate roots of the brachial plexus are affected, while the upper and lower escape.

243. **Paralysis of First Dorsal Root.**—The cases described by Lewis Jones‡ of atrophy of the intrinsics of the hands in young persons may be assigned a position as cases of root paralysis from disease of the first dorsal spinal root. They show atrophy of the intrinsics of one or both hands; the median and ulnar muscles are affected together, although the muscles in the forearms supplied by these nerves may escape. A reaction of degeneration is often present. Pain, if complained of, is referred to the area corresponding to the first dorsal sensory root, as has been pointed out by E. F. Buzzard,§ who has described some cases of the same character. Many of these hand atrophies are due to the presence of a cervical supernumerary rib exercising

* *British Medical Journal*, 1903, vol. ii., p. 1035.

† *Ibid.*, October 22, 1904.

‡ "On Symmetrical Atrophy of the Hands in Young People," St. Bartholomew's Hospital Reports, vol. xxix., 1893.

§ "Uniradicular Palsies of the Brachial Plexus," *Brain*, 1902, p. 299.

pressure upon the first dorsal root. W. Thorburn* first suggested that the existence of a supernumerary rib was the cause of this form of paralysis, and he showed X-ray photographs of two examples.

Other papers dealing with cervical ribs and their relationship to atrophy of the intrinsic muscles of the hands will be found in the *Lancet* † and in the *Quarterly Journal of Medicine*.‡

244. **The Lower Limb.**—Cases of paralysis from disease or injury of the nerves of the lower limb are much less common than they are in the arm. I have notes of only a few instances. In one recorded case there was paralysis of the front leg muscles from the pressure of a leather pad upon the peroneal nerve just below the head of the fibula. The patient was a man who walked daily upon stilts, which were strapped tightly round the legs just below the knee, and so set up the pressure upon the nerve.

Other cases may follow injury about the knee-joint, gunshot wounds of the thigh, or fractures through the lower third of the femur, and the operation for the relief of genu valgum may cause injury to the nerve trunks. The most usual seat of the injury to the nerve trunks of the lower extremity is in the external popliteal nerve or the peroneal nerve. This was the case in the following instances. The pressure occurred during occupation. In one, a carpenter sat on the ground with one leg doubled under him ; in the other, a leather-sewer fixed her work against the under side of a table, holding it there by the upward pressure of the left knee against the outer side of the right knee, which was crossed over the left one. In both there was pressure upon the peroneal nerve.

Penetrating wounds of the sciatic nerve or of its two divisions may occur. In one which came under my observation a boy slipped when walking upon the top of a glass-covered wall, and fell in a sitting posture. A piece of the glass pierced the under side of his thigh, divided the external popliteal branch, and lacerated the internal branch.

Neuritis of the sciatic nerve in its upper part, or of its lumbar

* "The Seventh Cervical Rib and its Effect upon the Brachial Plexus," Medico-Chirurgical Transactions, vol. lxxxviii., 1905, p. 109. "The Symptoms due to Cervical Ribs," *Medical Chronicle*, December, 1907.

† Hinds Howell, *Lancet*, June 22, 1907.

‡ Lewis Jones, *Quarterly Journal of Medicine*, January, 1908.

or sacral roots, may also cause paralysis and atrophy of leg muscles. Sometimes the onset of these cases resembles a severe sciatica (§ 257), and is quickly followed by foot-drop or other evidence of muscular paralysis. In other cases a partial paralysis coming on without pain may be observed, and is probably due to a localized affection of the anterior cornual grey matter of the cord. These conditions are rare.

The presence of some increase in the knee-jerks, and an incomplete paralysis of several muscles may be taken as signs that such a form of paralysis is central and not peripheral. The results of treatment in these cases are not good, whereas with peripheral cases they are generally satisfactory.

245. **Pes Cavus.**—This condition may occur from atrophy of the interossei. But many cases of *pes cavus* on electrical testing show the reactions of the interossei to be normal, and the deformity in these cases seems due to spasm of the long flexors and long extensors rather than to weakness of the intrinsics of the foot. Cases of this kind are seen in young persons, with a history of gradual onset, and both sides are commonly involved. When the knee-jerks are increased and the leg muscles are large and firm, and the interossei give normal reactions, the cases are suggestive of primary spastic paraplegia. In these cases electrical applications do no good.

246. **Multiple Neuritis.**—The clinical importance of neuritis is much more commonly recognised to-day than it was a few years ago, thus fully justifying the words of Remak in 1860, when he wrote, "I am convinced that medical practitioners will soon recognise that neuritis is a pathological condition which occurs more frequently than is usually believed." At the present time the general public have adopted the word, and now speak of their "neuritis," where formerly they would have spoken of their "rheumatism."

In the electrical treatment of multiple neuritis the question of the choice of method turns largely upon the presence or absence of severe pain or of acute symptoms. Clinically one meets with cases of neuritis characterized by marked paralysis and little or no pain, as in neuritis due to lead or following diphtheria, and again with others in which there is much pain, as in alcoholic and arsenical neuritis. Pain felt in the nerve trunks is probably a pain due to implication of the nervi nervorum, and should be distinguished from pain felt in the area of distribution of the

nerve, which indicates irritation of the conducting fibres proper of the nerve trunk itself. The presence of much pain in a case of neuritis demands mild currents.

If the neuritis is a general one, or is due to a general cause, even though its manifestations are local, the bath method of application, with mild, rhythmic sinusoidal currents, should be chosen whenever it is to be had. Thus, the toxic forms of neuritis, as for example, neuritis from alcohol, arsenic, lead, etc., and neuritis following diphtheria, influenza, or other general infections can best be treated through the medium of the general bath. No doubt it promotes the elimination of poisons in addition to its stimulating action upon the nutrition of the damaged tissues.

247. **Alcoholic Neuritis.**—General applications by means of the bath and sinusoidal current are most convenient in the treatment of this condition. I have notes of several cases where the patients at the commencement of the treatment were quite helpless, and showed a marked reaction of degeneration in many muscles, in whom good voluntary power, normal reactions, and well-nourished muscles returned during the time of their electrical treatment. It may be said of this disease, as of so many other forms of neuritis, that it has a natural tendency towards recovery, provided that alcohol can be withheld and the patient managed on general principles, but this does not in any way detract from the advantages to be derived from electrical treatment, which has a most distinct effect in promoting recovery.

Besides the typical cases of alcoholic polyneuritis one may often observe cases of a local neuritis in which alcohol is a predisposing cause or is acting prejudicially. Pressure palsy of the musculo-spiral nerve is especially seen in persons addicted to alcohol. The influence of alcohol in delaying recovery in cases of simple traumatic neuritis may also be commonly observed.

In other cases it may be difficult to decide whether a neuritis is primarily due to alcohol or to some other cause, as for example, gout, for both influences may be at work in the same individual.

248. **Gouty Neuritis.**—What has been said of alcoholic neuritis and its electrical treatment, applies with equal force to gouty neuritis. The general bath method, with rhythmic sinusoidal

current, may be employed with advantage. The use of local baths with lithium salts dissolved in the water has been already referred to (§ 201), but ionization of the affected region with salicylic ions is the method of choice. High-frequency currents are also useful by their general effect upon the system. The local treatment of a neuritis due to gout is likely to prove ineffective if the patient is allowed to continue in a general gouty condition, with recurrent articular attacks. On this account general treatment by diet and by drugs must also be attended to.

249. **Rheumatic Neuritis.**—The term "rheumatic" nas been applied to facial paralysis coming on after exposure to cold, and to other instances where exposure to cold or wet has appeared to be the direct cause of a neuritis. Sciatica (§ 257) is probably in many cases a form of rheumatic neuritis. Neuritis of the circumflex nerve, the so-called "deltoid rheumatism," is another (§ 256). Salicylic ionization or high frequency (diathermy) should be used. Dental sepsis should be looked for.

250. **Neuritis from Lead-Poisoning.**—In paralysis due to lead the reaction of degeneration is usually present, and is an early symptom. The partial reaction of degeneration is also often seen in some of the affected muscles, and others may show only simple quantitative diminution. Erb has pointed out that from the long duration of lead paralysis and the frequently occurring relapses, the condition of the electrical excitability may be considerably complicated. In cases of long standing the reactions become very difficult to elicit. Treatment by electricity is of prime value, for muscles which have lost their electrical irritability almost completely may be seen to recover it under this treatment, which needs to be long continued to obtain good results. Although some writers have advised the constant current almost exclusively in lead cases, Duchenne long ago showed by practical trials that a cure can be affected by coil currents also. He stated that in lead palsy recovery will follow the treatment almost always, even if the irritability to the induction coil current has completely disappeared from the muscles.

For the ordinary type of case with double wrist-drop the treatment usually employed by myself is the sinusoidal current, given by means of the arm-bath, with a rhythmic interrupter (§ 82) in the circuit. It is always followed by improvement,

and recovery will be complete except in old broken-down patients where the affection is of long standing. In the more severe cases of lead-poisoning the full length bath may be used as well, to favour elimination of the metal.

When the lead-poisoning is a result of the patient's occupation, he should be advised to give it up altogether, otherwise relapses are almost certain to follow.

To determine which of the extensors of the wrist are affected in cases of wrist-drop, the patient is told to raise the forearms and pronate them. If the muscles are all three of them paralyzed there is then no power of extending the wrist at all. If the extensor carpi radialis brevior can act, extension of the wrist is possible when the fingers are first flexed. If only the extensor carpi radialis longior, or the extensor carpi ulnaris, can act, then slight extension is associated with a lateral movement to the side of the acting muscle. Although the supinator longus usually escapes in wrist-drop due to lead, it does not always do so. The deltoid is sometimes affected. If the lower limbs are affected the peronei become most readily paralyzed.

251. **Arsenical Neuritis.**—General neuritis may be produced by arsenic in medicinal doses or it may follow a single large dose. As an instance of the latter the following is of interest: A prison warder in Ceylon was poisoned by a dose of arsenic in May, 1896. He survived the immediate effects of the poison, although they were very severe, and six days later felt numbness of the extremities, which extended until there was general loss of power. He could not stand, nor feed himself, nor button his clothes. The bladder was not affected. In October he came to England and could then stand and walk a little. Knee-jerks were absent, reactions showed partial RD in many muscles of the lower limbs. Upper limbs normal in quality. He was treated by general electrization (sinusoidal baths) and slowly recovered. He is noted to have shed the nails of his toes several times during his illness.

A case of poisoning from arsenic given medicinally is the following: A girl aged ten, with chorea, to whom arsenic had been given in 10-minim doses for five weeks, became paralyzed in all her limbs. The legs were most affected, and the front muscles more so than the calf or peronei. RD was present. There was great wasting, some pigmentation of the skin, and great pain in the limbs. She made a good recovery the girth measure-

ment of the calf increasing by $2\frac{1}{2}$ inches between March and November.

Coleman* has reported a similar case, also in a girl of twelve years, who was treated for chorea with arsenic during a month, the daily dose being equal to 45 minims of liquor arsenicalis. At the end of that time the chorea had ceased, and the child seemed in good health; but a fortnight later she had complete paralysis of the extensors of the feet, with RD, and partial paralysis of the extensors of the wrist and fingers, with simple decrease, but no RD. She recovered under the influence of rest, massage, and electricity. Similar cases are met with from time to time.

Recently a correspondence in the *Lancet* has suggested that the treatment of extensive burns by picric acid dressings may sometimes be followed by nervous symptoms, and in one case under treatment in the Electrical Department of St. Bartholomew's Hospital brachial neuritis seemed to be due to the liberal use of this material.

252. **Septic Neuritis.**—The occurrence of a local attack of neuritis in the course of diseases associated with septic states is not very uncommon. Cases have been described by numerous writers. I have myself seen one, probably of this class, in which a facial paralysis developed after confinement. Its symptoms differed in several points from ordinary "rheumatic" facial paralysis. It was associated with pain and numbness in the side of the face, and recovered very slowly and imperfectly. There was no exposure to cold nor ear disease or other local mischief to account for its coming on. Again, a patient who was being treated for stricture by the passage of catheters was taken ill with fever, for which he was admitted to Guy's Hospital. On his recovery he came to St. Bartholomew's Hospital with a paralysis of the right serratus magnus, which had come on during his illness. He made a good recovery. In another case a nurse developed an ulnar neuritis after infection of her chapped hands by pus while assisting at the opening of an abscess.

Gonorrhœa has been recorded several times as a cause of neuritis. A case has been reported, with many references, by Dr. Allard.† The patient had loss of power in the lower limbs, impaired sensation in the same regions, with pain and tender-

* *British Medical Journal*, January, 1898.

† *Archives d'Électricité Médicale*, June, 1898.

ness of sciatic and crural nerves, and showed great simple decrease to coil and to cells in the muscles of the legs, but no RD. The symptoms came on a fortnight after the appearance of a discharge, and were followed a few days later by inflammation in one ankle-joint. The neuritis was treated by electricity. The patient recovered. Ménetrier has reported a case which proved fatal. Profound changes were seen in the peripheral nerves and in the spinal cord.*

A form of neuritis which is very painful, and very slow to yield to treatment, is that which occurs in parts which have been the seat of suppuration, and is not uncommon after whitlows or poisoned wounds of the hand. The crippled condition which is left in these cases, though partly due to a matting together of ligaments and tendons, is also in part due to the existence of neuritis. Sometimes it is difficult to decide whether nerves may not have been divided in the incisions necessary for the evacuation of abscesses, and electrical testing should be called in for an answer. But although incisions may sometimes have divided some branches of the nerves and in that way may have contributed to the paralysis, it is generally possible to show by electrical testing that neuritis exists in the areas of nerves which cannot have been injured by the knife, while the testing may show that the ulnar or the median intrinsic muscles are damaged in unequal degrees and do not show signs of complete division. In such a case it might not be difficult to infer that there was no severing of the nerve trunk. Again, one may be asked whether the loss of power is due to an actual inflammatory process in the nerves, or whether it may not be due to compression of the nerves by cicatricial tissue. To answer this question one must look for signs of neuritis outside the area in which such cicatricial compression can be effective.

In painful amputation stumps we have another instance of neuritis, either septic or due to scar tissue compression, and in these cases there is often clear evidence of a neuritis extending upwards beyond the area of the scar.

The electrical treatment of these cases is slow. I have notes of several of them who have attended for a twelvemonth before completely losing their pains. Some relief is quickly felt from the applications, which are best carried out by means of the arm-bath with the sinusoidal current or the continuous current,

* **Abstract in *Lancet*, July 9, 1904.**

the latter being perhaps superior to the former. Although the results come so slowly, it is none the less surely. Gradually the texture and aspect of the skin return to normal, the adhesions soften, and the pain diminishes progressively and disappears. When scar tissue seems to be compressing the nerves, ionization with chlorine ions should be used.

253. **Neuritis from Syphilis.**—Neuritis is sometimes met with in syphilis, and the following is a striking case: A man came under treatment in December, 1892, with partial paralysis in the right arm. There was marked wasting of the biceps, and the grasp was much diminished in power. He had pains on the inner side of the arm. On his chest was an indolent patch of late syphilitic ulceration. In two months he had recovered, but not long afterwards he returned with sciatica, and a few months later came again with neuritis in the other sciatic nerve. In 1894 he reappeared with facial paralysis. Finally, in 1896, he came for the last time with hemiplegia. He was in a wretched condition, and had been for several months laid up in a country infirmary.

It is difficult to estimate the value of electricity in syphilitic neuritis, because the drug treatment in this disease is adequate. Electrical applications are probably useful, and should certainly be employed as an adjuvant in all cases.

254. **Neuritis after Diphtheria, Influenza, Beri-Beri, etc.**—These cases may show an extensive implication of many nerves or only a local neuritis. It is probable that in all of them the effect of general electrization by means of the electric bath is useful, by reason of its effect upon the general toxæmic condition, upon which they depend; good results also follow local treatment when the neuritis itself is a local one. A neuritis following a specific infection will sometimes persist in the most obstinate way in spite of all treatment, although, as a rule, they clear up quickly and thoroughly. For example, I would mention a case of simple neuralgia of one anterior crural nerve which followed an attack of influenza, and only wore away gradually and slowly, apparently uninfluenced by treatment, and took a twelvemonth before its complete disappearance. Happily, such unfavourable cases are not the rule. If it had been treated with ionization it might have done better.

Neuritis has been recorded after most, if not all, of the specific fevers. After typhoid fever a local neuritis is not very rare. It

is possible that some of the slighter cases of local neuritis after severe illness may be of the nature of pressure paralysis or sleep paralysis (§ 237).

The electrical reactions in all these forms of neuritis vary between simple decrease of irritability and the complete reaction of degeneration. The latter is found in the more severe cases.

It may not be out of place to mention that neuritis i not the only nervous disorder which may complicate or follow the specific fevers. Hemiplegia or disease of the lateral columns, or of the anterior cornua of the cord, may also occur, and as all of these conditions are decidedly more unfavourable than simple neuritis, it is important to make sure of the diagnosis in every case.

255. **Perineuritis.**—The distinction between pain in the area of distribution of a nerve and pain in the course of a nerve trunk has already been touched upon. In the latter case the disorder is most probably situated in the interstitial tissues or sheaths of the nerve trunk, and the pain is an expression of the implication of the nervi nervorum in the morbid process.

Most of the painful affections of nerves may be classified either as referred pains or as perineuritis. Cases belonging to the first group may be treated successfully by induction-coil applications, which relieve by their action as a counter-irritant, but the method is by no means suitable for painful neuritis or perineuritis, as we have already stated. The treatment of tender nerve-trunk cases is an important part of electro-therapeutic practice, but is by no means a simple matter, for in many instances the affections which come under this category are of an obstinate character. Sciatica and brachial neuritis are two familiar types of painful neuritis for which electrical treatment is frequently applied, and though they are common disorders, there is a certain degree of misapprehension as to the principles to be followed in applying treatment.

It is a commonly accepted notion that massage is good for these disorders. Gymnastic exercises, too, are often recommended as a means of obtaining relief, and patients will often persevere with these kinds of treatment in spite of an increase of pain as a result of doing so.

The cardinal principles upon which the treatment of painful neuritis should be founded are rest, warmth, and electricity, and the latter must be used for its ionic and vasomotor effects.

and not as a stimulant of muscular or nervous activity. The direct current or high frequency (diathermy) must therefore be used so long as there is any pain in the nerve trunks when the affected limb is at rest. When the later stages of the case are reached, and pain is felt only during certain movements, the activity of the congestion or inflammation is less severe, and the sinusoidal current, administered rhythmically through the medium of the monopolar or dipolar bath, is a useful mode of treatment.

256. **Brachial Neuritis**.—This is a common form of nerve-trunk pain, and one which may last a long time. The usual causes are injury or exposure to cold; while gout, alcohol, rheumatism, or syphilis may be predisposing causes. Dental sepsis must always be looked for.

It is important to exclude pressure from aneurysm or new growth, before making a diagnosis of simple neuritis. A common instance of brachial neuritis is the pain in the shoulder formerly called deltoid rheumatism, which is a neuritis of the circumflex nerve.

In other cases the neuritis may involve a greater or lesser part of the brachial plexus, and the pain may be severe. Thus, in one patient who was under my treatment, a light touch in the axilla was sufficient to cause violent shooting pains, which were felt down the arm and forearm, and even in the hand.

The important points in the treatment of brachial neuritis are to prescribe rest, warm applications, and with electricity, the ionic or thermal methods. Induction-coil applications, massage, and exercise are bad, and tend to make the condition worse. This is especially the case when there is pain even during quiescence of the limb. Both in brachial neuritis and in sciatica this forms a useful means of estimating the severity of the case. When they are acute, the pain is felt even when the limb is at rest, and often it is severely felt during the night-time. If, on the other hand, the pain is only felt during movement, the case may be considered to be less serious.

257. **Sciatica**.—This term is applied generally to pain felt in the region of the sciatic nerve, and it covers several distinct conditions. The pain may be due to pressure upon the nerve within the pelvis, and it is well to remember that sciatica due to this cause is sometimes noticed in early pregnancy. New growths also give rise to sciatic pain, and this must be borne

in mind, particularly when the pain complained of shows a progressive increase in severity.

Sciatica may be a referred pain or neuralgia, and Head has pointed out that affections of the prostate may cause a referred pain whose distribution resembles that of true sciatica. The same may be said of piles or anal fissure. Pains due to arthritis of the hip-joint are often confounded with sciatica.

In most cases the affection giving rise to the pain of sciatica is a perineuritis of the trunk of the sciatic nerve or of the lumbar plexus.

Sciatic perineuritis is best treated by diathermy, with the electrodes placed upon the loins and upon the calf, or on the lower part of the thigh. Applications should last for half an hour, and the current may be one of half an ampère or more, according to the thickness of the limb. Large pads, well wet with salt solution, must be placed between the electrodes and the skin, and must be firmly applied.

Direct applications of high frequency, by means of one pad applied in the same manner, are also of use in the treatment of sciatica, if a current of 500 milliampères or more can be obtained with the condenser couch. The electrode is to be bandaged on under the thigh.

Ionization with salicylic ions has also proved valuable. A large folded towel applied along the line of the nerve in the thigh should form the negative electrode, and the other is to be applied across the loins. Currents up to 100 milliampères for half an hour may be used.

In clinical practice the treatment of sciatica is often very tedious. Patients will often drag on for months with an old-standing sciatica which no treatment appears to relieve. The reason for this is not difficult to understand. In the early stages of sciatica there is congestion or inflammation of the nerve trunk, and the pains are not usually so acute as to compel the patient to lie up. Consequently, the limb does not receive the rest which is essential to recovery, the congestion is increased by the actions of standing, of walking, and of sitting, until eventually adhesions may be formed between the nerve and the surrounding tissue, or a thickening of the sheath of the nerve may be caused by the long-continued congestion, and this thickening tends to interfere with the nutrition of the nerve. Moreover, it commonly happens that massage is tried in an early

stage of the attack, or the patient may try to "walk off" the complaint. The result is that cases of sciatica of long standing are abundant, and are very difficult to relieve by electrical treatment of any kind.

In early sciatica the urgent need of rest should be insisted on so long as the pain in the trunk of the nerve is felt during conditions of repose.

When the acuteness of the attack is subsiding, and pain is only felt in movements of the limb, a very valuable treatment is that of the electric bath with sinusoidal current. This gives relief to very many cases, and a test which will determine whether sinusoidal baths are suitable for the case can readily be applied by giving a bath and observing the effect. If the patient finds that the application provokes the sciatic pain, the nerve is still too sensitive to bear this form of application. On the other hand, if the patient feels comfortable in the bath, the case is ripe for treatment on those lines.

The condition of a patient whose sciatic pain is due to adhesions is often deplorable. The pain goes on for month after month, in spite of applications of various kinds, and the question of treatment is a very difficult one.

It is quite certain that adhesions may cause sciatic pain, and that the breaking down of an adhesion may be followed by the disappearance of the sciatica.

Thus a patient of mine who had had sciatica for nearly twelve months experienced a sudden pain in the back of the thigh. It occurred as the result of a careless movement made while he was dressing himself. So severe was the pain that he went back to bed, but in a few days the pain had subsided and his sciatica had disappeared.

An operation for the exploration of the nerve and the division of any adhesions found will often put an end to a sciatica due to this cause. The operation of nerve-stretching was no doubt a method of breaking down adhesions, but it was accompanied by considerable risk of injury to the nerve fibres, and is now less often practised. A better operative procedure is the division of any adhesions found, and perhaps the longitudinal splitting of the sheath of the nerve, if that is found to be thickened.

The possibility of breaking down adhesions by massage or manipulation of the limb should be borne in mind before deciding upon a surgical operation. As the employment of massage

in early sciatica has already been condemned, it will be seen that procedures considered injurious in early cases of sciatica may be of prime value at a later stage of the complaint, and the difficulty will be to decide when any given case is to be treated according to the one method and when according to the other. In a general way it may be considered that pain occurring only on movement, and especially if it occurs only with special movements, is due to adhesions. Massive ionization over the tender area with chlorine ions may be used in the later stages of sciatica. Ammonium chloride may be used with advantage instead of sodium chloride.

258. **Meralgia Paræsthetica.**—This name is given to a painful numbness of the outer side of the thigh. It is a neuritis of the external cutaneous nerve (see Plate X.), and is brought on by pressure, or by a blow or other injury upon the trunk of the nerve. R. Morton* has described three cases, one of which was that of a barrister who frequently struck his thigh at the same spot in passing through a swinging gate in Lincoln's Inn Fields. Sometimes it is due to the pressure of a badly-fitting corset. Miller† has described such a case, and I have also seen one due to the same cause. The pains may be very severe, and the numbness quite distinct. In the case under my care ionization with salicylic ions rapidly relieved the symptoms, although treatment by ordinary electrical currents had previously been used for many weeks without good effect.

259. **Neuralgia—Referred Pains.**—The word neuralgia is applied to many different conditions in which pain is felt in the course of the area of distribution of a nerve, and the term might perhaps be defined as pain in the region of a nerve in which no inflammation or other morbid state can be discovered. The pain of neuralgia is also generally an intermittent pain. It is well known that a neuralgic pain in one part may be set up in a reflex way by irritation acting upon some more or less remote part. A familiar instance is the trigeminal neuralgia so often excited by disease of a tooth, and severe supra-orbital pain may be instantly produced in some people by the eating of an ice. Neuralgia of the testis from renal calculus is a form of reflex neuralgia. Headache from digestive disorder is another.

* *Lancet*, March 28, 1908.

† *British Medical Journal*, Epitome, 1911, No. 346.

Head * has shown that the whole surface of the body can be mapped out into areas, each of which corresponds to certain visceral organs. In cases of referred pain we are enabled through Head's researches to form useful opinions as to the probable position of the irritation concerned in any given instance, and this greatly increases the chances of successful treatment.

An important point in true referred pains is the frequent presence of cutaneous tenderness. This has been pointed out by Head and Mackenzie, and is especially insisted on by them as a valuable means of distinguishing between referred and other forms of pain.

When we compare sensory with motor nerves we find an analogy between anæsthesia and paralysis, and between neuralgia and muscular spasm. The two latter are especially associated with irritation, direct or reflex, of sensory or motor nerves or nerve centres. And we may also learn from the comparison of motor and sensory phenomena that, just as in the case of paralysis, the lesion producing it may be in the motor fibres or the ganglion cells, or in the motor tracts of the spinal cord or brain, so too in the case of sensory disturbances the lesion producing them may occupy any part of the sensory tract, peripheral or central. For example, the neuralgic pains which follow herpes zoster are due to changes in the posterior root ganglion. It is therefore necessary before arriving at any final opinion as to the cause of a neuralgic pain to explore all those parts so far as is possible.

In all cases of neuralgic pain it is of especial importance to examine carefully for the possible existence of pressure or deep-seated inflammation of nerve trunks as a cause of the pain. Thus a brachial neuralgia may be due to new growths of the cervical vertebræ, and sciatica to inflammatory processes or new growths in the pelvis.

The electrical treatment of painful affections takes either of two different directions. In the treatment of referred pains and true neuralgias the principle of counter-irritation is followed, and by the production of painful cutaneous impressions it is sought to create a diversion, as it were, in the nature of the impulses conducted along the nerve, and so by influencing the centres to remove the neuralgic condition. Counter-irritation is

* *Brain*, 1893, 1894, Parts 61, 62, 67.

a very popular treatment for neuralgic pains, and induction-coil currents afford a counter-irritant of great convenience in application, because they do not damage the skin in the way that blisters or strong liniments or the cautery do. The term "neuralgia," however, is often applied to conditions which are due to neuritis or perineuritis.

260. **Trigeminal Neuralgia.**—The areas supplied by the fifth cranial nerve are often the seat of referred pains. These are excited by disturbances in many parts of the head, neck, and face. The nose, the eye, the ear, the teeth, the tongue, the salivary and other glands, the tonsils, the larynx, and lastly the brain itself, are enumerated by Head as sources of referred pains in the trigeminal or other areas of the head and neck. Neuralgias of the head and neck are also produced by irritations coming from many of the viscera. When it is remembered how large a part of the thoracic and abdominal viscera receive a nerve supply from the vagus or the glosso-pharyngeal nerves, which are of cranial origin, this connection between disturbances of the viscera and referred pains in one or other area of the head and neck becomes intelligible.

Pain in the area of the fifth cranial nerve may be due to a "rheumatic" neuritis, and these cases are often very severe. A method of treatment by electrical applications, devised by Bergonié, consists in the use of very large currents applied by means of an electrode which is so shaped as to cover the entire side of the face. If care is taken to mould the electrode carefully to fit the surface, and if the currents are gradually increased and reduced, magnitudes of 40 or 50 milliampères can be borne without discomfort and without damage to the texture of the skin. The duration of each application may be half an hour, and it must be repeated daily until the tendency to paroxysms of pain has disappeared.

Bergonié's method was the forerunner of an analogous treatment by ionization, in which the same large electrodes and large currents are used. Very good results have followed the treatment of severe trigeminal neuralgic pain by the introduction of ions of salicylic acid or quinine.

Leduc* has reported the cure of a case of this kind after it had for four years resisted other remedial measures. A single

* *Archives d'Électricité Médicale*, July 25, 1904.

application of the ions of quinine produced permanent relief. The following is an abstract of the case:

A female, aged sixty-eight years, previously healthy, developed, after exposure to cold, an acute attack of convulsive tic. The pain, which was constant, but subject to very frequent exacerbations, was limited to the area of distribution of the submaxillary branch of the left trigeminal nerve. The paroxysms were irregular, set up by a multitude of causes, mental and physical, and more especially by cold. For four years prior to undergoing electrical treatment she was unable to handle anything cold—much less take a cool drink—without experiencing an immediate exacerbation. Hyperæsthesia of the skin was so marked that the slight variation in temperature caused by the opening of a window was sufficient to provoke a paroxysm. Her rest at night was greatly disturbed. She had tried all kinds of medicaments in large doses without experiencing any relief. Every tooth, although sound, on the affected side was sacrificed, but without effect. On September 20, 1902, the nerve was divided, after which the attacks ceased for four days, only to recur with the same frequency and intensity. In March, 1903, a resection of the alveolar border of the lower jaw proved equally ineffective. On February 25, 1904, when she consulted Dr. Leduc, her condition was as bad as could be. The introduction of salicylic ions was first tried, and twelve applications were made, but owing to her great distress the sessions had to be cut short and a current of too low a strength employed. This treatment afforded her some relief, and the frequency and intensity of the paroxysms were reduced, whilst the period of sleep was extended. On June 3 ionization with bichloride of quinine in 1 per cent. solution was applied, with a current gradually raised to 20 milliampères for thirty minutes, and gave rise to an œdematous redness of the skin, but resulted in a marked diminution of the pain and the number of the attacks, as well as in an increase of sleep. The improvement was even more marked on the two following days. On June 5 she had two small reminders; these were the last. On June 6 the parts were much discoloured and desquamating; hyperæsthesia very much reduced. A second application was made by way of precaution, and since then she required no further treatment, being absolutely free from pain.

Since then many observers have recorded excellent results

from ionization. In general, salicylic ions should be tried first, but quinine is also valuable. I have had a series of very good results in my own practice. Neuralgia after herpes zoster does not usually respond favourably, the lesion causing the pain being deeply seated in the Gasserian ganglion, and therefore inaccessible, whereas the favourable cases are probably neuritic and situated in the peripheral parts of the nerve.

261. **Great Occipital Neuralgia.**—A neuritis of this nerve is met with occasionally, and may give much pain. In a patient of my own the pain began suddenly while he was stooping down and straining himself to strap a portmanteau. The distribution clearly pointed to the right great occipital nerve, and the pain caused by it was severe, and when seen had lasted for several months. After a few ionizations with salicylic ions it completely disappeared.

262. **Acroparæsthesia.**—This name is given to a condition which is common in out-patient practice, and appears to have been first described as a clinical entity by J. A. Ormerod.* The patients are generally women between the ages of forty and fifty-five years, and they complain of feelings of numbness and tingling in the hands and forearms. The symptoms are especially noticed in the morning on awaking from sleep, and patients often say that they are in the habit of rubbing their hands when they wake in order to bring sensation back. A dull aching or burning feeling is also complained of, and some muscular weakness is present. Rarely there may be a little wasting of the intrinsic muscles of the hands. Treatment by arm-baths with sinusoidal or interrupted current gradually removes the trouble, though it may last for several months. Bromides are useful as a drug treatment.

263. **Myalgia.**—This is the name given to those pains which are felt in over-fatigued muscles; when patients are in a condition of debility, the amount of muscular exertion which sets up these myalgic pains may be so small that the connection between them and their true cause may be entirely overlooked. Hence myalgia is constantly confounded with hysteria, rheumatic, spinal, and other diseases.† The symptoms are pain in the muscles, made worse on movement, and tenderness. The

* "On a Peculiar Numbness and Paresis of the Hands," St. Bartholomew's Hospital Reports, vol. xix., 1883, p. 17.

† Inman on "Myalgia," Churchill, 1860.

skin over the muscles may also be very tender. The pains are often referred to one of the tendinous insertions of the affected muscles, and the trunk muscles are most commonly affected. Dr. Inman mentions as common seats of myalgic pains (1) the trapezius at its insertion into the occipital bone and into the spine of the scapula; (2) the spines of the dorsal and lumbar vertebræ (origins of spinal muscles); (3) the front of the chest (origin of pectoralis major and minor) producing infra-mammary pain; (4) at the margins of the ribs, or at the pubes (insertions of recti abdominis).

Myalgia may exist in persons who are apparently healthy, and it may be difficult to decide what is the particular cause of the muscular fatigue which they suffer from; at the same time their pains may be very obstinate and very troublesome, and may resist all treatment until the diagnosis is clearly established, and rest for the affected muscles can be contrived. The movements which specially aggravate the pain must be carefully ascertained in order to decide upon the exact muscle which is at fault. General electrical applications may so improve the tone of the muscles as to enable them to perform without fatigue the work they are called upon to do. Local treatment acts usefully, too, by improving the circulation in the muscles. The rhythmic induction-coil current, or sinusoidal current, should be used. Erb has advised the use of continuous currents up to 20 milliampères, and this suggests that the ionic interchanges associated with steady currents are valuable to improve the nutrition of the feeble muscles.

264. **Sprengel's Deformity.**—This peculiar condition has already been mentioned in § 233. It consists in an elevation of the scapula, as though due to spasm of the rhomboids and trapezius, but is really due to a congenital defect in the thorax. Skiagrams show very abnormal ribs, which may be connected to one another, or bifurcated, or irregular in thickness. The vertebræ may be irregularly developed, and there may be a bridge of bone connecting the scapula to the lower cervical vertebræ. At one time it was thought that the bridge of bone was the cause of the faulty position of the scapula, and operations have been performed for its removal; but it is often absent. Fig. 167 shows the back view of an adult with this condition. More often these cases are seen in young children, and are thought to be the result of some injury to the shoulder at birth; but a

skiagram clears up the diagnosis by showing the extensive developmental defects. Both sides of the thorax may be affected, and both scapulæ may be permanently displaced upwards; but

FIG. 167.—CONGENITAL ELEVATION OF RIGHT SCAPULA: SPRENGEL'S DEFORMITY.

usually one shoulder is affected. See *Archives of the Roentgen Ray* (June, 1911) for photographs and skiagrams of cases; also a paper by D. Greig,* for a good account of the condition, with photographs, skiagrams, and bibliographic index.

* *Edinburgh Medical Journal*, March, 1911.

CHAPTER XIII

THE NERVOUS SYSTEM—THE SPINAL CORD AND BRAIN

X rays in spinal cord diseases—Syringomyelia—Anterior poliomyelitis—Locomotor ataxia—Hemiplegia—Paralysis agitans—Acromegaly—Chorea—Tetany—Hysteria—Mental disorders.

265. **The Spinal Cord.**—Much effort has been devoted to the electrical treatment of chronic spinal cord diseases, such as tabes, disseminated sclerosis, chronic myelitis, and so on, but beyond a certain degree of temporary relief of symptoms in some cases, the results have not been of any special value. In the last few years X rays have been tried, and the results obtained have been rather better.

Although the bony coverings of the cord would appear to present an obstacle to the penetration of the rays, it seems that the neuroglia in a state of pathological activity is highly sensitive to X rays, while the resisting power of the nervous elements also encourages the application of vigorous X-ray treatment. Raymond,* in 1905, first reported good effects in syringomyelia. In 1906 Babinski† observed a considerable amelioration of symptoms in a boy with general contracture which came on after a motor-car accident, and was thought to be due to pachymeningitis of the cord. In this case the X rays were used for obtaining radiographs, and by reason of the difficulty of obtaining good pictures, because of the boy's faulty cramped attitudes, a number of successive X-ray exposures had to be made. These were followed by a notable improvement in the boy's symptoms. The X rays were continued, and the patient recovered.

* "Sur la Guérissabilité de la Syringomyelie," *Journal des Practiciens*, 1905.

† "De la Radiothérapie dans les Paralysies Spasmodiques Spinales," *Bulletin de la Société Médicale des Hôpitaux de Paris*, March, 1907 (see also *ibid.*, December, 1906).

Since then X rays have been tried in disseminated sclerosis, spastic paraplegia, compression paraplegia (Pott's disease), and in tabes, also in acromegaly, and with encouraging results.

The mode of application consists in the use of penetrating rays; Benoist No. 6 or upwards (§ 144), filtered through 1 millimetre of aluminium, and directed upon the spine from both sides of the middle line alternately by a method of "cross fire." A dose of 3 H. is given, and this is repeated daily for four or six days, and followed by an interval of three weeks before being repeated. A sheet of lead, pierced by a slit measuring 25 by 4 centimetres is used to localize the rays upon the side under treatment.

266. **Syringomyelia.**—The first recorded case of the arrest of this disease by X-ray applications is stated by Beaujard* as being in good health five years afterwards. This case, originally reported by Raymond, and treated by Oberthur and Delherm, was that of a girl of fifteen, with typical syringomyelia, and great muscular weakness. Beaujard also gives one of his own cases as follows: A young man of twenty-three began to have weakness of the left hand, with atrophy of the hypothenar muscles, four years before. A year later he lost the terminal phalanx of his right index finger through a painless whitlow. When first seen he had clawed hands with interosseal atrophy, most marked on the left side, but with more trophic changes (fissures and ulcers) on the right hand.

The loss of perception of heat and cold was well marked in the whole of both upper limbs, and over a good part of the thorax. In 1905 he was treated by regular applications of X rays once a week, from May until the end of the year. After the third application his sensory defects began to improve; after the fifth the fissures and ulcerations of the right hand commenced to heal, and his muscular power increased. Next his symptoms all improved; his exaggerated reflexes became normal, and treatment was discontinued. Later he showed signs that the X rays had not been applied sufficiently high up, for he began to develop symptoms of syringomyelia of the medulla such as facial anæsthesia and loss of taste. Five further X-ray applications dissipated these symptoms, and the patient has since remained well for three years.

Many other writers have recorded cases of syringomyelia in

* *Archives d'Électricité Médicale*, March 25, 1910.

which X rays have done good. Cases of long standing are naturally less favourable than those of more recent onset. The amount of recovery possible in any case must depend upon the degree to which destruction of nerve elements has actually advanced, but the X rays seem certainly to arrest the further progress of the disease. The perception of heat and cold appears to return less early and less completely than the tactile sensation and the muscular power.

267. **Disseminated Sclerosis.**—In this disease intervals of quiescence, or of apparent recession of symptoms, are often seen, and on this account it is difficult to feel quite sure that the treatment used is really the cause of any observed improvement. Several writers have recorded cases in which improvement seemed to follow X-ray applications. Marinesco* has reported one in a man aged twenty-nine, who showed all the signs of disseminated sclerosis in an advanced degree, and was markedly benefited by a course of X-ray treatment in respect of the tremors, of the speech, and of the power of walking. His ability to write had been quite lost but was recovered. The improvement took place during a month of treatment, with applications every two or three days. Different parts of the spinal cord were irradiated, chiefly the cervical and the lumbar regions. The applications were for about ten minutes, with a current of 1 milliampère, at a distance of 15 centimetres. A second case, a woman aged twenty-eight, showed similar improvements; a third case showed no result. Beaujard has recorded two cases which improved distinctly under treatment. Other observers have not found any appreciable benefit.

268. **Lateral Sclerosis.**—Under this term, or that of spastic paraplegia or chronic myelitis, several conditions are included, which have the common character of spastic gait, increased reflexes, and some slight degree of impairment of the sphincters. Often there is backache, and this may be the symptom which first causes the patient to seek medical assistance.

The X-ray treatment of these conditions has yielded some favourable results, though not very many. An interesting point to observe in the recorded cases is that in several relief has been given, but has been followed by relapse some months later. Beaujard has mentioned a case of this kind. There was a relapse after two months, and the symptoms were again re-

* *Archives d'Électricité Médicale*, 1910, p. 241.

lieved by six irradiations, but three months later there was another relapse, without relief from further treatment.

269. **Myelitis.**—Electrical treatment is certainly useful when, as the result of an attack of acute myelitis, a patient is left with weakness of the bladder or of the lower limbs. I have seen the systematic application of direct currents longitudinally along the spine produce very definite improvement in such cases. Thus, in one case the patient, three years after the acute attack, could walk only with difficulty; his back muscles were so weak that he could not sit up for more than a few minutes at a time, and his sphincters were uncertain. He has so far improved under treatment as to be able to walk for several hours a day, to go shooting, and to play lawn tennis.

In his case the treatment has been by direct currents applied longitudinally along the spine. His manservant was taught how to carry out the applications, which were given regularly for ten minutes daily. The improvement was slow, but has been continuous from the time when the electrical treatment was begun. Sinusoidal treatment in baths also seems to be useful in some of these cases.

270. **Anterior Poliomyelitis.**—There is no doubt that electrical treatment is of the utmost value for the development of muscles damaged by this disease. From the result of an electrical testing which has shown seriously impaired reactions, many children have been thought to be beyond the reach of treatment; but it is quite certain that prolonged electrical treatment will do good to nearly all cases of infantile paralysis, particularly if not more than a year or two has been allowed to go by since the incidence of the disease. Even after that lapse of time something may still be done.

There is a formula in which the prognosis of infantile paralysis has been commonly summed up. It is as follows: If the ganglion cells supplying the muscle are destroyed, recovery must be impossible, and if the cells are not destroyed, treatment is unnecessary, because the patients will get well of their own accord. This formula is widely accepted, but it has done much harm. It requires the assumption that the disease must either destroy all the motor cells of a muscle, or else must leave them all uninjured, and this assumption is certainly not correct. On the contrary, the damage to the motor nucleus may be of any degree of severity or of any extent, and the paralysis may

vary between slight weakness and complete loss of all motor power.

It is reasonable to suppose that a focus of disease in the anterior cornu of the cord may destroy some of the nerve cells of the nucleus of origin of a muscle, while others in the same nucleus may escape, and this might especially be the case if the nucleus of origin is an extensive one. On this point the statements of Sherrington are conclusive. In the Medico-Chirurgical Transactions, vol. lxxxii., p. 456, he writes: "The position of the nerve cells sending motor fibres to any one skeletal muscle is a scattered one, extending throughout the whole length of the spinal segments innervating that muscle; in the limb regions many muscles receive their motor fibres from as many as three consecutive spinal roots, and the bodies of the nerve cells innervating those must, therefore, inside the cord, extend through the length of three whole segments of the cord as a continuous columnar group, and in each transverse level of the cord these cells must lie commingled with nerve cells innervating many other muscles."

This being so, one can readily understand how a muscle may be crippled by poliomyelitis, and yet may survive in part through the support of such of its ganglion cells as happen to have escaped destruction.

Duchenne long ago pointed out that a muscle damaged by infantile paralysis may still contain a few living functional muscle fibres, and that these may easily be overlooked in an ordinary electrical examination of the muscle, but that they can be successfully cultivated by persevering treatment. There is no doubt that cases admitting of such an interpretation do occur.

If the surviving fibres can by cultivation be made numerous enough to have some useful voluntary power, they will be able to maintain themselves in a way which is impossible to them if they are unable to do any work. I had an opportunity of testing and dissecting the muscles in an amputated leg, the seat of severe infantile paralysis of old standing. The age of the patient was twenty years, and the limb had been paralyzed from childhood. The muscles of the leg were all extremely atrophied, degenerated, and fatty—in fact, the calf was almost like adipose tissue, but still contained a sufficient number of normal muscle fibres to show visible contractions to the induction-coil current. The other muscles of the leg, though in a state of advanced

atrophy, all contained some fibres which were able to respond either to the induction coil or to the battery current. These reactions showed that even at that time there must have been some surviving ganglion cells in the affected portion of the cord, and that a certain degree of trophic nervous influence was still available for the muscles of the paralyzed limb. Its hopeless condition at the time of the amputation was the result, not only of the old attack of poliomyelitis, but also of the sixteen years or so of disuse, and it is probable that sedulous treatment by electricity, gymnastics, and massage in childhood would have enabled the limb to recover sufficiently for it to have been of some use to its owner.

The persistence for several years of reaction of degeneration in cases of old infantile paralysis is a peculiar phenomenon, and implies, I believe, that the muscles showing it are not without some representation in their spinal centre. In cases of complete division of a nerve trunk, the muscles cease to react at all to electricity in a year or less, but in infantile paralysis a well-marked reaction of degeneration may be demonstrated ten or twelve years or more after the original attack; and this is a clear distinction between the condition of a muscle cut off completely from its nucleus of origin by section of its nerve, and a muscle paralyzed and wasted by severe poliomyelitis.

Among muscles damaged by infantile paralysis three degrees of injury may be noted. In one the muscles are wasted, but they present reactions which, though weak, are normal in quality both to the induction coil and to the battery current. In the second group the muscles are paralyzed, atrophied, and show a reaction of degeneration, while the third group show no visible reactions at all.

It can be said of the first group that they tend to recover spontaneously, but if left to themselves recovery is slow and imperfect. Under treatment they usually advance more rapidly, even when the affected limb has been left very thin and weak.

It is well known that muscles paralyzed by poliomyelitis may recover spontaneously, but may remain in a state of imperfect recovery, even though their electrical reactions are normal, and these derive benefit from systematic electrical treatment. I have seen improvement start at once with treatment in a previously untreated case of fifteen years' standing.

With cases of the second class—namely, those with the re-

action of degeneration—it is quite a mistake to say that they are incurable, and that electricity can do nothing for them. Electrical reactions of normal quality, and useful voluntary power may return in muscles which for a long time have shown RD and loss of voluntary power, and this I have seen a number of times.

In a child with a history of paralysis which came on at the age of five months, treatment commenced in June, 1891; she was then three years of age. There were no reactions in any muscles of either leg, there was extreme wasting, and marked talipes equino-varus in the left foot. She was quite unable to stand. After three years' treatment her legs showed reactions to the induction coil in nearly all the muscles on both sides, and she could walk, though this was done in a rather awkward manner, because one quadriceps extensor muscle remained thin and weak. This case affords a clear instance of the good effect of electrical stimulation upon the nutrition of greatly enfeebled muscles, which at one time seemed to have fallen into the last degree of atrophy and paralysis.

I have notes of numerous cases in which normal reactions and voluntary power have returned in muscles long paralyzed with RD.

The following illustrates this class of case:

C. F., onset of paralysis in 1894. When seen in the same year there was RD in front muscles of right leg, with feeble normal reactions in the peronei, and no reaction of any kind in the calf muscles or in the tibialis posticus. Next year there was slight return of voluntary power. In 1899 voluntary power was much greater, and there were normal reactions of good quality in the peronei and the front muscles of the leg, with the return of a reaction (RD) in calf and tibialis posticus.

The best mode of treating infantile paralysis is that proposed by Bergonié, and already indicated in the section dealing with electrical testing (§ 212). Its value consists in the simplicity of its application and in the utilization, without pain to the patient, of strong currents and long daily applications. The limb is arranged as for testing (Fig. 161), but the patient is kept warmly covered, while rhythmically interrupted currents are sent through the whole length of the limb. Bergonié states that he has gradually come to prolong the duration of an application, from observing the improved results obtained, until he now gives two daily applications, each lasting from half an hour

to an hour. There is not the slightest evidence of any fatigue or exhaustion from these long sittings, but, on the contrary, nothing but good follows them. The form of current to be preferred will depend upon the condition of the muscles; when they respond to sinusoidal or induction-coil currents these will be used, and when they show a reaction of degeneration, the current will be drawn from a direct current source; but in either case they must be rhythmically interrupted, either by the metronome or by one of the rhythmic interrupters already described. Bergonié prefers a metronome which gives reversals of current, with two impulses per second.

When the lower limbs are the seat of paralysis, as is usually the case, the electric bath is an excellent method of applying this treatment, as the hot water keeps the patient warm. The child, dressed in a short waistcoat, is put into the bath in a sitting position. The current is very well borne in this way, and the whole extent of the paralyzed parts comes simultaneously under treatment. The strength of the current is gauged by putting the hands into the tub, one at each end, and by watching the effect upon the child, the current being made weak at first, and strengthened gradually. It must be strong enough to cause movement of the muscles. This plan requires no special knowledge of anatomy; it is efficient and likely to be persevered in, and this point of perseverance over long periods of time is the key to success. Even if only one of the lower limbs be affected, there is no reason why the bath should not be used, and if the sound leg be flexed and drawn up, most of the electrical current is diverted into the other one.

In every case of infantile paralysis which is not clearing up satisfactorily, it is important to apply electrical treatment, continuing it for six months or a year or more.

It is the exception for a muscle to be so completely destroyed by poliomyelitis as to be left without any functional fibres, and these remaining fibres can be cultivated by persevering stimulation of them.

Where the muscles show only the reaction of degeneration, or even when reactions are entirely abolished, some improvement may be hoped for in a good percentage of cases.

The amount of restoration which is possible in a muscle will depend upon the number of surviving ganglion cells. With prolonged treatment recovery advances very much farther than

one might expect, and is infinitely superior to the results obtained when treatment has not been given.

Even where the electrical reactions are not altered in quality, it is not good practice to leave the case to take care of itself.

The first signs of improvement are a better circulation in the affected parts, disappearance of chilblains and sores, and a gradual gain of voluntary power.

The return of electrical reactions comes later, and it is usual, when all contractility has been lost, for a weak reaction to the induction coil to return first. This means that the few latent normal fibres in the wasted muscle have begun to grow and to gain sufficient strength to produce a visible contraction.

At the first examination the muscles are tested carefully, and the result is recorded, the girth of the affected limb is measured, the voluntary power of the paralyzed muscles is ascertained and any faulty attitude of the limb noted. A note must also be made of the colour of the limb, its temperature, and whether chilblains or scars of chilblains are present or not. The nurse or the mother must be instructed as to massage. She must also be shown how to exercise the weak muscles by means of appropriate movements, and must take pains to make the child try to do its best to move the limb accordingly. If irons or other orthopædic appliances are worn, the child is to be made to exercise its limbs without them for a certain time each day.

Instructions must also be given as to maintaining a proper warmth of the cold limbs. Recovery is greatly retarded by cold.

271. **Locomotor Ataxy.**—X-ray applications have yielded some results in tabes. Bordier* has recorded one in which the patient lost Romberg's sign (the inability to stand steady with closed eyes), and ceased to have the Argyll-Robertson pupil. He was able to resume his duties as a cavalry officer. The treatment lasted six months, and consisted of six series of X-ray applications to the cervical, dorsal and lumbar spine, and he estimated the amount of radiation actually received by the spinal cord as 6 I. (§ 145) during that time. In discussing the fraction of the total irradiation which penetrates to the cord, he states that by means of experiments made with a skeleton, and having pads of cotton wet with normal saline to represent the muscles and soft parts, he found that a pastille within the vertebral canal

* *Archives d'Électricité Médicale*, November 25, 1911.

received ½ I. when the skin surface underneath 1 millimetre of aluminium received 2 I. if the irradiations were directed obliquely, so as to avoid the vertebral spines.

Labeau* has reported five cases of tabes in which some improvement followed X-ray applications after five, six, or eight sittings.

Several of my patients with very definite signs of tabes have seemed to derive some benefit to their symptoms from a course of general electrization by means of electric baths. In others the application of direct currents to the spine has seemed to be of service, and it is this mode of treatment which has generally been adopted. The electrodes are applied at the dorsal and lumbar regions. Many writers on electrotherapeutics have been able to bring forward instances of relief to symptoms from electrical applications in tabes. In the *Archives d'Électricité Médicale* of 1893, the notes of thirty-seven cases are collected together from various sources by Dr. Laborde, and the whole subject of the electrical treatment of tabes is critically examined in a paper which forms a valuable contribution to the subject. His summary accords with my own experience that the treatment of the spinal cord by direct currents does not cure tabes, but in certain cases it can relieve the pains, the ocular disorders, the weakness of the limbs, or even the bladder troubles. Induction-coil currents seem to act unfavourably. Bilinkin† has given a number of instances in which the evidence on this point seems clear.

For the laryngeal, gastric, and vesical crises of tabes the same writer recommends galvanic currents with electrodes upon the nape of the neck and the lumbar spine. He uses large currents, even up to 90 milliampères, and considers them free from danger.

The usual precautions necessary in applications of large currents must be rigorously observed, no sudden interruptions or variations of current being permissible. The electrodes must be firmly fixed, the skin well protected by thick, wet cloths. The positive pole is applied to the neck. A few applications suffice. If applied during the crisis, it is arrested within a few minutes. Bilinkin also recommends the use of direct currents of large magnitude to the joints of the lower limbs, and gives instances

* *Annales d'Électrobiologie*, October, 1911.

† *Ibid.*, 1911, 1912.

in which this procedure had a very marked good effect upon the power of maintaining equilibrium with the eyes closed.

272. **Progressive Muscular Atrophy.**—The electrical reactions differ in the different forms of progressive muscular atrophy. In the myelopathic forms the gradual degeneration of the muscle, fibre by fibre, produces a condition in which some fibres may still react normally, while others respond only by a reaction of degeneration. Thus, it is sometimes possible to recognize in an affected muscle a quick contraction followed by a sluggish one, the latter being produced by the degenerated fibres and the former by those which are still sound. As the degenerated fibres soon waste away, the final stage of an affected muscle is a stage of extreme atrophy, without any visible reactions at all.

In the neuritic "peroneal" or "Charcot-Marie" type, it is possible to observe a reaction of degeneration in some of the affected muscles. In general, however, the muscles in this form of atrophy show simple diminution to coil stimuli, and normal behaviour to cells. The diminution of response to induction-coil currents may be extreme, and there is also a great diminution in the sensory perception of induction-coil currents. As atrophy advances, all the reactions become increasingly difficult to provoke.

In the myopathic forms of atrophy the reaction of degeneration is not observed, and the only changes noticed are quantitative, simple decrease or total loss of response to coil and to cells being the rule, except in the early stages. Bourguignon and Huet have recently found that in myopathic patients an examination of muscles which are apparently not yet affected by the atrophy reveals certain deviations from the normal. The opening contraction KOC (§ 167) is readily produced, and duration tetanus is set up with ten, or even with five milliampères in some instances.

In none of the diseases included in the general title of progressive muscular atrophy can it be said that the prospects of cure by electricity are good. In the spinal forms Erb considers that he has seen relief, retardation, and even arrest of symptoms, especially in early cases, and advises treatment of the spinal cord. His method is to use the direct current, treating particularly the cervical enlargement, which is frequently the seat of the most severe atrophic changes. The affected muscles are also to be treated by interrupted currents.

He considers myopathic atrophies to have a more favourable prognosis, as he has seen great benefit follow electrical treatment in cases of that kind. Duchenne* states that by means of induction-coil treatment he had been able to arrest the progress of the disease in an advanced case (which seems to have been undoubtedly one of "myelopathic" progressive muscular atrophy) to re-establish the power of the diaphragm, which had become seriously involved, to restore the bulk and vigour of an important muscle (the biceps), and to dispel the fibrillar twitchings, and that the recovery was persistent for several years, in spite of the fact that the patient returned to hard manual labour —a condition of things extremely likely, in Duchenne's opinion, to bring on a relapse. He is certain that he has seen an increase in the bulk of a wasting muscle from coil applications, but only in cases where the muscle had not altogether lost its irritability to coil currents.

273. **Myasthenia Gravis.**—Cases of this disease may come under the notice of those interested in electrotherapeutic matters because of the peculiar reaction (the so-called myasthenic reaction) which is met with in the muscles of such patients (§ 225). The peculiarity consists in a rapid decrease in the amount of response shown by a myasthenic muscle when it is tetanized continuously by the interrupted current. In other words, a myasthenic muscle shows the ordinary physiological effect of fatigue with excessive and abnormal rapidity, so far as the tetanizing effect of the interrupted current is concerned; but in spite of this, it may remain just as responsive to the application of a single closing shock from a direct current source after the tetanization as before.†

274. **Hemiplegia.**—In the less severe cases of hemiplegia good results are commonly obtained by electrical stimulation of the affected limbs, and this is a very valuable fact, because so little can be done in other ways to improve the condition of old hemiplegic patients. I have seen great benefit produced by the electrical treatment of such cases, and that not once or twice only, but frequently. In hospital practice the difficulty with old hemiplegic cases is rather to know when treatment may be

* "Électrisation Localisée" (third edition), p. 500, description and figure.

† "The Clinical History and Post-mortem Examination of Five Cases of Myasthenia Gravis," E. Farquhar Buzzard, *Brain*, 1905, p. 438.

discontinued, for as a rule the patients seem to wish to continue attendance indefinitely. Improvement up to a certain point is the rule. After that continued treatment does very little. Much cannot be expected when there is well-marked late rigidity. The series of cases recorded by Professor Erb seems to show that after an attack of hemiplegia the muscles may remain in a crippled condition from a sort of torpor of some part of the motor tracts, so that they remain for a time beyond the control of the will, although there may be no absolute interruption in the conducting paths. Thus, a patient may at once recover much of his lost power after a single vigorous electrization of his affected limbs. It is therefore very important that this treatment should always be tried in cases where a patient is recovering imperfectly from hemiplegia. Treatment should not be commenced until a fortnight or more after the attack, in order to allow the period of acute disturbance to pass off, and it may be repeated three times a week. A certain number of patients will be distinctly improved thereby. Most of the improvement likely to be obtained in this way may be expected to show itself in the course of the first month. It is also urged by Leduc* that treatment be directed to the seat of the lesion in the brain, the continuous current being employed, the kathode to the forehead and the anode to the nape of the neck, with steady currents, avoiding all interruptions or accidental variations. A current of 20 milliampères is recommended, and the active electrode should be the usual folded cloth, as used for ionization, and securely attached by a band round the head. This treatment is to be carried out daily or every other day, the duration of each sitting being about fifteen minutes, taking several minutes to turn the current on and off. As the morbid process in the brain is essentially a destructive one, there must be limits to the amount of recovery which is possible. These limits will be determined by the extent and the situation of the damaged part. Leduc† has also published four cases in which marked amelioration followed the treatment.

275. **Epilepsy.**—This has been attacked by electrical methods, but without any great advantage. Arthuis stated that he had seen good results follow from electrostatic treatment.

Althaus gives three cases where treatment at once diminished

* *Zeitschrift für Elektrotherapie*, 1903.

† *Annales d'Électrobiologie*, March, 1901.

the frequency of the attacks, and went so far towards effecting a cure that the intervals between the fits were prolonged from a few days to two months. Erb also reports that he has received a decidedly favourable impression from the treatment of epilepsy by the constant current. He advises that the anode be placed first on the side of the forehead, with the kathode to the nape of the neck, with a weak current for one minute; and, secondly, in the middle line of the head in front with the same current, and for the same length of time, the kathode being over the occiput. The treatment of the seat of the aura as well is recommended by Althaus.

Branth has suggested the use of X rays in epilepsy, and has reported a case of mixed *grand* and *petit mal* originating in childhood, in a man aged thirty-one, in which very decided benefit seems to have followed a course of X-ray treatment.

276. **Paralysis Agitans.**—An interesting case of the cure of this condition has been reported by Doumer and Maes.* The patient was a farmer aged seventy-two. His trouble began two years previously, with an attack of cerebral congestion, during which he was insensible for two days. No paralysis followed, but his general condition gradually declined from that time. Trembling of the hands began, and extended to the forearms and arms. It was of a rhythmic character, and interfered not only with writing, but with all use of his hands. The lower limbs were next invaded, and his gait assumed a character of trepidation. His attitude became bent, his trunk muscles rigid. His blood-pressure was found to be notably increased, and on this account he was treated by autoconduction. After a month of daily treatment the tremors had entirely disappeared, his hypertension had also disappeared, and all his other symptoms had gone.

The idea occurs to one that possibly autoconduction currents were set up in the brain, and had exercised some peculiar trophic action there, as well as by their effect upon the patient's blood-pressure.

277. **Acromegaly.**—Béclère has recorded a case of acromegaly treated by X rays, with arrest of headache and relief of ocular troubles, of vertigo, and of nausea and vomiting. He states that the growth of the bones was arrested, the genital functions were restored, and the weight of the body diminished.

* *Annales d'Électrobiologie*, 1905, p. 620.

278. **Chorea.**—Statical electricity has been successfully used in the treatment of this disease. In 1849 Dr. Golding Bird* strongly advocated its use, and reported thirty-seven cases. Of these thirty had been cured by the treatment, while five of the others were relieved. The treatment adopted was the application of sparks to the spine. The patients were insulated and connected with one of the conductors of the electrical machine. A ball-electrode with insulated handle was attached to the other conductor, and sparks were applied to the spinal column and the affected limb, until a papular eruption was produced. In the case of children the mother or nurse was insulated with the child in her arms, and sparks were applied to the child's back and limbs as before.

The shocks from a Leyden jar were found to be harmful.

In Guy's Hospital Reports in 1853 Sir William Gull reported twenty-five cases of chorea treated by statical electricity. Nineteen were cured and five improved; only one resisted the treatment. He says: "The fact stands well established that electricity is at present to be ranked amongst the means at our disposal for the cure of chorea, and that in severe cases its effects are often truly surprising. Where other means cannot be employed; when the patient is scarcely able to swallow; where the skin is abraded from the prominent bones of the emaciated frame; when the powers of life seem nearly exhausted, sparks of electricity drawn from the whole length of the spine will often, after a few repetitions, effect a favourable change, and enable us to administer other means of cure." In spite of this emphatic testimony, the treatment is nowadays neglected.

In the few cases which have come under my own notice I have found such statical treatment very useful. It is possible that the anæmia of the brain, which has been invoked to explain the movements of chorea, may be benefited by the rise of blood-pressure which is associated with statical treatment.

With modern machines the negative breeze to the spine will alarm the patient less and will prove equally efficacious.

It often happens that patients seem to recover imperfectly from chorea, because certain habitual movements remain when the disease has otherwise disappeared. For these late symptoms electrical applications are very suitable. I have seen them quickly dispelled in several such cases by a course of electro-

* "Lectures on Electricity and Galvanism," London, 1849.

static treatment with sparks. Indeed, all those which I have been asked to treat for this condition have recovered within two or three weeks.

The paretic states which are often left after chorea may be treated by rhythmic currents with great advantage.

General electrization in the electric bath is also useful.

279. **Spasm and Tremor.**—The numerous forms of tonic and clonic spasm and of tremor often come under electrical treatment by reason of their incurable character. When the symptoms are due to paralysis agitans or disseminated sclerosis, the methods just considered (§§ 267, 276) may be tried. Other forms of spasm and tremor, which may be of central origin, are relieved by electrical applications to the head and neck. The treatment is usually very slow to yield a favourable result. Erb has recorded a number of cases from his own observation and that of others.

Hysterical cases sometimes improve quickly under electrical treatment. Statical applications are perhaps the most suitable form of treatment for them.

It must not be forgotten that spasmodic affections are not infrequently reflex phenomena. Thus, there may be severe spasm of the muscles of mastication from inflammation about the gums or throat, and inflamed cervical glands sometimes cause wry-neck. Or there may be spasm from direct irritation of the nerves, as in wry-neck from disease of the cervical vertebræ. Before commencing electrical treatment a careful examination should be made for any source of irritation, and this, if possible, must be remedied.

In children and also, though less commonly, in adults wry-neck may be due to exposure to cold or wet, and this form has been called "rheumatic," and yields easily to salicylic ionization.

280. **Writer's Cramp.**—This is the best-known form of a series of spasmodic affections which are produced by prolonged over-work of certain muscles, particularly when the work done is of a complicated and highly co-ordinated kind. The name of function spasm or occupation spasm has been given to this group. Besides those whose occupation is writing, violinists, piano-players, tailors, and shoemakers are subject to similar attacks in the muscles which they use most often. The symptoms of writer's cramp are also seen sometimes in persons who do not

write much. In writer's cramp there is a spasm associated with muscular weakness, pain, and tremor, either of which may predominate. The chief seat of the cramp or palsy is in the intrinsic muscles of the thumb and first finger. If the occupation be persevered with, other muscles are called on to take the place of those which are deranged, and soon they also suffer.

The characteristic feature of these affections is that the weakness, or pain, or spasm, is produced only by one particular kind of work. The hand of a man with writer's cramp remains useful for everything except writing, and so with the other forms of true occupation spasm.

The results of electrical treatment are unsatisfactory. Probably the best treatment would be galvanization of the brain, with longitudinal currents, and the kathode to the forehead.

Max Weiss,* in discussing the electrical treatment of writer's cramp, recommends the use of constant currents of from two to five or eight milliampères, for fifteen to twenty-five minutes with absolute rest from writing; applications twice daily during the first weeks, diminishing later to two or three times a week. Anode in the palm if extension is the main symptom, on the dorsum if flexion. Kathode to be placed on the nape of the neck or on the upper and inner part of the arm. The anode may also be applied to the tender points for ten to twenty minutes. Treatment to the motor cortex and to the spine at the lower cervical level should also be used.

281. **Tetany.**—This form of spasm, although not very common, deserves mention here, because of the peculiar increase in electrical irritability which forms one of its leading symptoms. There is also, as is well known, an increased irritability of the nerves and muscles to mechanical stimulation, and this is not confined to any particular nerve, although it has been most commonly observed in the facial nerve (facial irritability). The peculiar spasms can be evoked by compression of a nerve-trunk or of the main artery of a limb, or by a rough touch over a motor nerve. Erb first showed that the electrical irritability was also increased in this disease.

In a recent paper Dr. Bernhardt has reported three cases in which the electrical reactions were examined. His results, compared with the normal irritability of the same nerves, are

* *Centralblatt für die gesamm. Therap.*, April, 1891.

represented in the following table, which gives the current in milliampères required to produce the first KCC contractions.

Nerve.	Normal.	Tetany (3 Cases).
Facial - - -	0·9—3·0 milliampères	0·5 —1·5 milliampères
Median - - -	0·9—3·3 ,,	0·25—1·5 ,,
Musculo-spiral -	2·0—5·0 ,,	0·25—1·0 ,,
Peroneal - -	1·0—2·0 ,,	0·5 —1·1 ,,

ACC and KDT (kathodal duration tetanus) were also more easily produced than usual. "In the electrical treatment of tetany the influence of the anode stabile is to be directed to the affected parts, and the current must be gradually diminished at the termination of the sitting to avoid the ill effect of sudden anodal opening." The results of treatment are said to be entirely favourable, but the disease is one which tends to disappear spontaneously.

281A. **Headache.**—The headaches of debility and fatigue are often dispelled at once by static charging, and they may be brought on by high-frequency applications in some cases. The condition of the blood-pressure should be examined, and used to determine the treatment, using static applications if the pressure is low, and high-frequency if it is high. In migraine there is no adequate electrical treatment, but constant current applied longitudinally to the skull has been suggested.

282. **Insomnia.**—General electrization frequently produces a tendency to sleep afterwards. The electric bath has an especially strong effect in predisposing to sleep; so has the static charge (positive) with head breeze. Bonnefoy has pointed out that statical applications are specially indicated in subjects with a low arterial pressure, and are unlikely to be of service in the opposite condition of raised arterial tension.

High-frequency applications, which have a tendency to reduce blood-pressure, should be chosen in preference for patients of this latter class; and W. F. Somerville has stated that they often prove efficacious. He uses the method of the condenser couch, with currents ranging between 200 and 700 milliampères in the case of women, and slightly larger currents for male patients.

283. **Hysteria.**—Hysterical affections have been very largely treated by electricity, and, from the peculiar nature of the affec-

tion, good results have followed the most diverse forms of electrical treatment. The moral effect of the treatment, particularly when it is associated with sparks or with shocks, is suitable to the state of mind of hysteria, and therefore the literature of Medical Electricity, from the time of John Wesley's "Desideratum" onwards, is full of more or less wonderful cures of such cases by electricity, acting no doubt in a psychical way. At the same time the action of electrical treatment lies rather in the direction of dispelling symptoms than of curing the morbid state, and it is necessary to be prepared for occasional difficulties and disappointments even in hysterical cases, although good results will often be obtained. We must also be careful not to claim too much for the electrical part of the treatment when it is successful, for it may happen that the touch of an electrode will cure even when there is no current. Several cases of this kind have come to my notice. Strong shocks have often been used for cutting short a hysterical fit, but the most useful rôle of electricity in hysteria is for the removal of paralysis, anæsthesia, or spasm; for these symptoms the induction coil is most usually employed, either with an ordinary electrode or with a dry metallic brush. Statical treatment, especially the treatment by sparks, is also valuable in these cases, and has been very largely practised.

Hysterical aphonia can sometimes be dispelled by coil currents applied to the throat from outside, and for the most part this method is as good as the direct application of the electrode to the fauces or to the larynx.

The electrical treatment of hysterical symptoms does not depend merely on the severity of the applications. The treatment may be briskly applied, but pain must not be deliberately inflicted. In the treatment of functional aphonia by sparks or shocks there are cases where the patient becomes alarmed and screams out aloud, and so becomes cured. Others suffer in silence and do not cry out, and these are not so easily cured.

For the hysterical condition, as distinguished from the special symptoms, it is advisable to use general electrization, and especially the electric bath or treatment by statical charging and breeze.

Hysterical patients are considered to be bad subjects for high-frequency treatment.

An important consideration is the diagnosis between hysteria

and organic disease of some obscure kind. It is not at all uncommon for hysteria to be associated with serious disease—for instance, with phthisis. Moreover, when the diagnosis of hysteria has been based upon the complaint of a persistent localized pain in a female patient, it may, after all, turn out that the pain is due to some serious latent mischief. I have known two cases where female patients with early malignant disease of the vertebræ complained of persistent pain, and were supposed to be suffering from hysteria alone.

284. **Mental Diseases.**—The abundant evidence which we possess of the value of general electrization in the simpler forms of nutritional failure seems to point to the importance of applying the same kind of treatment in certain forms of insanity or mental failure, especially if the general state of nutrition is not maintained. As a rule, cases of this kind are not often met with in general practice nor among the out-patients of general hospitals, and it will rather be in asylum practice that opportunities for trying electrical treatment will arise. A considerable amount of evidence has already accumulated to show that something may be done in this way. A valuable summary of the position up to about 1885 will be found in Erb's work on Electrotherapeutics, together with numerous references to the writings which should be consulted in connection with the subject. Three cases which have come under my own experience may be mentioned here. One was that of a man referred to me by Dr. Gee, with a note saying that the patient showed many of the signs of progressive dementia, but that, as his symptoms dated from a recent attack of influenza, he might receive benefit from electricity. The patient recovered rapidly after a short course of sinusoidal bath treatment. He regained his memory, which he had completely lost, and was able to go back to his work. Another patient was a shorthand writer who had broken down in health completely. He was strange in his manner, and sat huddled up in a dejected attitude. His wife said he was much changed in temper, and told me that on one occasion he had been found wandering about, and had been brought home by a policeman. When he came he was put on sinusoidal baths twice a week. A gradual improvement began, and all his symptoms slowly left him. After three months he was able to begin work again, and has continued well for more than four years.

A third case is very much like the last. A man of forty began to grow more and more helpless. He became unable to find his way in the street; he stumbled easily, and several times fell down without adequate cause. His speech became slow, and he could attend to no business, and it was uncertain whether he understood what he read in the newspaper. Under electric bath treatment there was a slow improvement, perceptible first to his wife. In about two months' time he was able to come to the hospital alone instead of being brought there by a friend. Treatment was continued for nearly a twelvemonth, and during the last part of the time he was able to attend to the book-keeping of his wife's business. He spoke quickly and to the point, and no longer stumbled or fell down, and he described himself as "practically well." There was a gain in weight both in his case and in the preceding one.

The following communication from Dr. Robert Jones is noteworthy, as showing a simultaneous mental improvement and augmentation of body-weight in a series of cases treated under his supervision at Claybury Asylum by general electrical stimulation by the bath method, using induction-coil currents:

"I have tried the electric baths in the case of adolescents mostly. In these and others the form of insanity was that of melancholia, some of the cases presenting well-marked melancholia attonita.

"These cases are marked by a gradual deterioration as a rule. They stand or sit about in a fixed or passive attitude, and have almost always to be considerably coaxed (if not forcibly fed) in order to get them to take nourishment. The mental condition is so unsatisfactory that some persons call the disease primary dementia, and it is certainly not a very curable form.

"After my conversation with you and my encouragement by your method of bath treatment, I tried it upon eighteen males and five females. The record of weight in the case of the females was not kept; of the five cases all improved greatly in health; two were phthisical, but whilst undergoing bath treatment both gained several stones in weight. One died of phthisis; of the others, one was discharged recovered, one has developed epilepsy, and one has recovered sufficiently to lead a useful life as a helper in the asylum.

"Of the eighteen men, nine have left the asylum (six recovered, two relieved, and one improved but not recovered).

All the men gained weight under treatment (they were weighed weekly, and the record has been kept), the average gain of the nine who left the asylum being seven pounds during the bath treatment, which lasts for an average period of about seven weeks, but many received baths during nine or eleven weeks The greatest gain of one case whilst under treatment was twenty-two pounds, the next nineteen pounds. Of the nine cases remaining under treatment, one is phthisical, one is suffering from progressive muscular atrophy; the others are considerably improved mentally, the stupor or profound melancholia having quite passed off, but they have not been well enough to be discharged from the asylum. I consider the results to be satisfactory."

E. Goodall and Wallis* have reported upon the results in a number of patients treated by them with electric baths, and express the opinion that the results of this treatment were of benefit in a large percentage of their cases. They also noted an increase in the excretion of creatinine as a nearly constant phenomenon in cases treated by the electric baths. The paper is a valuable one, well "documented," and should be consulted.

* *Journal of Mental Science*, April, 1910.

CHAPTER XIV

THE CIRCULATORY SYSTEM—THE RESPIRATORY ORGANS—THE DIGESTIVE TRACT

The relief of congestion—Raynaud's disease—Intermittent claudication—Arterio-sclerosis—Laryngeal affections—Pulmonary tuberculosis—Œsophageal spasm—Constipation—Gastric dilatation—Exophthalmic goitre—Asthma—Hæmorrhoids—Rectal fissure and ulceration.

285. **Disorders of Circulation.**—General stimulation (§ 180) has been recommended in the treatment of some forms of cardiac neuralgia, in dilatation of the heart, and in cardiac dropsy. It is considered unsuitable for cases with marked arterio-sclerotic changes. Larat has advised the use of the sinusoidal current bath, and Cluzet mentions that improved compensatory changes, decrease of cardiac pain, reduction of anasarca, and better diuresis have been noticed in cardiac cases treated in this way. Caution should be observed at the commencement of a course of baths, as heart patients may show some dyspnœa or embarrassment of the heart as the result of immersion in the warm water. The temperature of the water should not be more than 93° F. at first, and the patient should enter and leave the bath gradually and cautiously.

The effects of electrical applications upon the blood-pressure have already been referred to in §§ 188, 189. The static charge has a decided influence in raising the blood-pressure, and its effect is increased by the brush discharge or sparks applied to the region of the spine. The effluve and spark discharge of high frequency applied in the same way to the spine is said to produce a rise of blood-pressure, whereas treatment by "autoconduction" (§ 133) or the condenser couch lowers the blood-pressure.

Bonnefoy* has pointed out the important bearing of the blood-pressure characteristics as a guide in electrical treatment.

* "De l'Insomnie," *Cannes Médicale*, 1903.

After mentioning the good effect which statical treatment has upon neurasthenic symptoms, and especially upon the insomnia of neurasthenics, he relates two cases in which static treatment aggravated the insomnia. He found that in both instances the patients had high blood-pressures, and he considered that the increase of their already high pressure by the static electricity had the direct effect of making their symptoms worse. By changing the treatment from static to high frequency he obtained a lowering of blood-pressure and a relief of the symptoms.

286. **The Relief of Congestion.**—The uses of electrical treatment for the relief of congestion and to promote the absorption of inflammatory products should occupy an important place in therapeutics.

This effect of electrical applications was investigated by Remak* in 1856.

He made use of the continuous current exclusively, and, so far as one can judge, the magnitudes of current employed by him were fairly large. There is no doubt that his views on the subject were correct, and that the direct current may be regarded as having a special power of improving the circulation in a part, and as being of great value in promoting the removal of œdema and of other chronic conditions due to inflammation. As an example of the effect of the battery current in relieving severe congestion caused by injury to a joint, the following case, reported by Remak, seems to be worthy of being reproduced in abstract:

"A washer-woman, aged thirty-six, fell from a table and felt her right foot to be twisted outwards; so much pain was produced that she could not walk. During the rest of the day and through the night she applied cold-water dressings. The following day she consulted Remak; she was obliged to drive to his house, and ascended the stairs with great pain and difficulty. He found the dorsum of the foot much swelled, livid, and very tender; the diagnosis made was laceration of some of the tarsal ligaments and extravasation of blood. The aspect of the foot was such as to lead to the apprehension that gangrene might result. At the patient's urgent request, electrical treatment was applied. Owing to the thickness of the skin of the sole of her foot, it was necessary to use a large number of cells in order to produce any sensation or reddening of the skin. By re-

* *Galvanotherapie*, R. Remak, Paris, 1860.

peatedly changing the place of application of the electrodes, he continued the application for twenty-five minutes. During this time the livid coloration disappeared, and the œdema and the pain diminished considerably. The warmth of the foot, increased by the current, continued until the evening, by which time a decided improvement was established, and she passed a good night without pain. Next day the colour of the foot was better and the symptoms were less severe; the treatment was repeated on this and on the next three days. She was then so much better as to walk without lameness, and in a fortnight was practically well."

The view taken by Remak is that the current produces a marked increase in the rate of circulation through the part treated, by a general dilatation of its bloodvessels, and as a consequence of the improvement in the circulation the products of effusion are much more rapidly carried off than would otherwise be the case. A. Tripier* has pointed out that the application of interrupted currents to the scrotum causes active pulsation in the vessels of the spermatic cord. He further shows that in general the application of interrupted currents provokes a transient hyperæmia in the part treated, and shows how this reaction can be turned to useful account in many conditions of defective circulation—for instance, in local congestions of many kinds.

Several writers have reported favourably of the absorption of fluid effusions in ascites and of hydrocele by electricity. In ascites the induction-coil current applied energetically for fifteen or twenty minutes so as to set up vigorous and repeated contractions of the muscular walls of the abdomen, has been followed by increased flow of urine and disappearance of the ascites. The prospects of permanent cure must depend upon the cause of the ascites in each particular case. In hydrocele the same result has been observed.

287. **Raynaud's Disease — Chilblains.**—The electric bath is useful in cases of defective circulation, as in Raynaud's disease, chilblains, cold feet, and in cases of ischæmia of the extremities. One of the first signs of improvement in cases of infantile paralysis is that the circulation is improved, the limb becomes warmer, and the chilblains disappear. The applications can be very

* "Contributions à l'Histoire Thérapeutique des Stases et Congestion Apyrétiques," *Annales d'Électrobiologie*, 1905, p. 624.

conveniently made by the bath method. Either a general bath or an arm-bath or a foot-bath can be used.

In the disease which bears his name Raynaud has recommended the constant current, and Barlow* has suggested its use by means of baths, and says that: "In a typical paroxysmal case, if the two limbs are similarly affected, it will be found that the limb which is subjected to the electric treatment will more rapidly recover than the one which is simply kept warm."

For chilblains the arm-bath or foot-bath with induction coil is the most convenient domestic remedy, and succeeds in all but the most severe cases. I have used this mode of treatment in a number of cases, and have repeatedly seen the prompt disappearance of chilblains follow its use. Moreover, patients have several times informed me that after the cure of their chilblains by a course of coil baths they have found themselves with more resisting power afterwards, so that a course of baths at the beginning of winter has been sufficient to get them through the whole of the cold weather without any return of the chilblains afterwards. The effect of the treatment, therefore, is more or less lasting. A rhythmic interrupter is a valuable aid. High-frequency local application can also be used.

Patients who know by experience that they are likely to have severe "broken" chilblains should not delay too long before beginning with the treatment, as the current acts very painfully upon any raw ulcerated surfaces. If these already exist; they must be protected during the bath with oiled silk, or some other waterproof covering.

288. **Intermittent Claudication.**—This condition is not yet universally recognized by medical practitioners, but the symptoms are characteristic, and the treatment by electricity is satisfactory. The complaint is that severe pain comes on in one or both legs after a certain amount of walking. It may be so severe as to compel the patient to rest, and with rest the pain ceases. If the walk is then resumed the pain returns as before, but sooner.

One of my patients said that he could walk around his billiard-table during the evening without any inconvenience, but that if he went out for a walk the pain stopped him before he had gone a mile. Another patient, who had suffered from phlebitis, jarred

* New Sydenham Society, "Selected Monographs."

his legs when getting out of a train, and pain came on about an hour later. He became lame, and was laid up for a fortnight. Since that time he always became lame after walking a hundred yards, but this went off after a rest. The pains were referred to the knee and to the hip. The symptoms disappeared after a course of electric foot-baths, with induction-coil currents.

These cases are due to a defective blood-supply to the muscles of the thigh or leg. Calcareous arteries have been diagnosed in some, thrombosis in others. The peculiar symptoms are due to the fact that the muscles receive a blood-supply which is sufficient for their needs when at rest, but not when they are in action. Treatment which improves the circulation in the affected limb relieves the symptoms, and may give permanent relief. Electric foot-baths with interrupted currents are sufficient to effect this in milder cases. High frequency has been recorded as very useful in a group of cases by Delherm and Laquerrière.* In some of these gangrene had threatened, and amputation of a gangrenous limb had been performed in one case, the patient seeking treatment for symptoms which had begun to appear in the other. The cases were successfully treated by high-frequency currents, the electrode being applied to the leg and foot. Diathermy is also indicated.

289. **Arterio-sclerosis.**—The reduction of the blood-pressure in individuals in whom it has been raised by disease has been particularly studied by A. Moutier, who holds the opinion that autoconduction by high-frequency currents provides a means of reducing arterial pressure and of securing a return to the normal in cases of permanent hypertension.

In a certain number of cases he has observed a reduction in the arterial pressure of 1 to 2 centimetres of mercury after a single sitting, but in general the normal degree of blood-pressure is obtained after six, eight, or ten sittings. If more are required, it is almost always due to one of the following reasons—viz., the existence of organic lesions, errors of diet, or constipation ; but he states that he has never failed to obtain normal readings after sixteen or twenty applications.

Many observers have been unable to confirm Moutier's views, and Bergonié (§ 189), as a result of careful experimental work, found that autoconduction does not lower the arterial blood-

* *Archives d'Électricité Médicale*, October, 1909.

pressure as a general rule. But it may do so, and from what we know now of its thermal effects and of the vaso-dilatory actions of warmth, it seems quite reasonable to expect a fall of blood-pressure in certain cases; for instance, Nagelschmidt has affirmed the production of a lowering of blood-pressure as a result of diathermal applications. Macnamara,* in a series of blood-pressure estimations in neurasthenia, found that high-frequency applications lowered the pressure in 267 cases, raised it in 30, and left it unchanged in 34. Bonnefoy,† in his work already quoted, has recorded a number of cases in which hypertension was reduced in a satisfactory manner by high-frequency treatment with the autocondensation method—a method to be preferred when it can be substituted for autoconduction, as it is more convenient in application. To obtain adequate results, large currents should be used, and if the palms of the hands are dry, it is an advantage to use moistened cloths between the metal handles and the skin, so that the currents entering from the handles encounter less resistance. An epigastric pad is also a good medium for the applications. Diathermal treatment with two electrodes may supplant the older D'Arsonval high frequency for the treatment of hypertension.

290. **Aneurysm.**—Electrolysis has been tried for the cure of aneurysms, particularly for those which are not suitable for treatment by ligature or compression. In many of the cases recorded some temporary increase of hardness has followed the operation, but the cures are but few, and the punctures made in the sac walls have sometimes led to hæmorrhage. The piercing of the wall of the aneurysm by the needles, with the consequent risk of bleeding, is the chief defect of the operation. It may be lessened by the use of needles insulated except near their point, so as to limit the electrolytic process to the interior of the aneurysm, and to prevent any action upon its wall.

The method which is generally preferred is to introduce both positive and negative needles into the tumour. Ciniselli‡ has collected twenty-three cases; of these six recovered, sixteen died, and one case disappeared from observation. Some of those reported as cured had relapses a few months later. See also

* *Lancet*, July 18, 1908.

† "L'Arthritisme et son Traitement." J. B. Baillière et fils, Paris, 1907.

‡ "Treatment of Thoracic Aneurysms by Electro-puncture," Milan, 1870.

British Medical Journal, 1890, vol. i., p. 1276, for a report of successful results after thirteen sittings in a case of aortic aneurysm.

As far as can be made out from the details furnished, the electrolysis of aneurysm requires large currents and long sittings. Twenty, thirty, or forty cells have been used, and the application continued for half an hour or more. Assuming the internal resistance to have been 100 ohms (it may have been much lower), and putting the electromotive force of the cells used at one volt apiece, then twenty cells would give a current of about 200 milliampères, and forty would give twice as much. This current, if continued for half an hour, would be sufficient to set free a considerable amount of electrolytic gases, and in some of the cases we read that the tumours became resonant to percussion after the operation. The free acids and alkalies produced by the electrolytic separation of the neutral salts of the blood would probably soon recombine in their passage along the blood-stream. The clotting set up in the aneurysm is soft and diffluent.

Willard* has reported a case in which 20 feet of silver wire were inserted into an aneurysm and a current of 80 milliampères passed through it. The results were favourable, and the patient was able to leave hospital nine weeks later. Dodsworth, of Brazil, has reported some cases in which simple galvanic currents through the chest appeared to relieve aortic aneurysm.

The diagnosis of aneurysm by X-ray examination is now comparatively easy, and it may be worth while to warn beginners against confounding the normal convex shadow given by the posterior portion of the normal aortic arch with the shadow given by aneurysms. This mistake has often been made because at a certain angle of incidence the shadow presents an appearance very like that of a small circular bulge at the level of the arch.

291. **Cardiac Failure.**—The aid of electricity is often invoked for the purpose of resuscitation when death appears to be imminent. It may be applied either in the form of brisk general cutaneous stimulation, as in cases of narcotic-poisoning, or with the special objects of stimulating respiratory movements or of acting upon the beat of the heart.

Direct applications to the heart region do not readily affect the movements of that organ. If they do, the result is quite as

* *University of Pennsylvania Medical Bulletin*, September, 1901.

likely to be harmful as useful. It is better, therefore, not to attempt it.

In order to act upon the respiratory centres, the use of the induction coil, either with moistened electrodes or with the metallic brush electrode, is advised. The region of the body which is stimulated is not of special importance; the applications may be made to any part which is exposed and convenient of access.

A considerable reflex effect is produced by this cutaneous stimulation, and if the wire brush is used there is less risk of producing fatigue or exhaustion of the patient, than if a short wire coil be used with moistened electrodes. Stimulation of the face, especially of the nose and upper lip, tend to act favourably upon respiration. Duchenne has shown that stimulation of this kind applied to the precordia or to the skin of the back in the lower dorsal region also influences the respirations. At the former situation inspiration is chiefly promoted, and in the latter expiration.

Frederick Taylor,* in discussing the treatment of opium poisoning, has recorded two cases in which he observed a marked good effect from general faradic applications, which effectually roused the patient from his comatose state after forty or fifty minutes. He used ordinary moistened electrodes to the trunk and limbs. No sign of exhaustion or fatigue was noticed. He suggests that the muscular contractions may aid in the elimination of the poison.

The phrenic nerves in the neck can be directly stimulated by the induction coil without difficulty, and contraction of the diaphragm will follow. No inconvenience seems to be produced by the proximity of the vagi. The method is as follows: Two moistened electrodes of small size, about one inch in diameter, must be connected to the coil; one should have a key for making and breaking the circuit. These are to be applied under the posterior border of the sterno-mastoid muscles, which should be pushed forward. The key must then be closed and opened rhythmically about every two seconds; each closure causes an inspiration, expiration being allowed to take place during the intervals. This use of the induction coil to set up respiratory movements may be advantageously combined with mechanical artificial respiration by Silvester's method. Elec-

* Proc. Roy. Soc. Med. (Therapeutic Section), 1912, p. 165.

trical stimulation of the phrenics in asphyxia and in chloroform-poisoning have been successfully carried out. Stimulation of the epigastric region may cause expiratory movements by acting upon the abdominal muscles.

Hampson's method (§ 172) may sometimes be useful.

292. **Other Cardiac Affections.**—Bonnefoy* has reported good results in the treatment by the condenser couch of cardiac hypertrophy, cardiac dilatation with emphysema, fatty heart, old endocarditis, and tachycardia. Rumpf† has advised applications to the precordial region by means of a glass condenser electrode of special type in cardiac dilatation and insufficiency.

Larat‡ states that the electric bath with sinusoidal current is of value in cardiac dropsy. By its use the anasarca is reduced, diuresis is increased, and the patient's condition is ameliorated. These favourable effects often appear rapidly, after three or four baths.

293. **Varicose Veins.**—The same author also reports on the good effect of electric baths in cases of varicose veins; but at present the method of choice for this affection, for varicocele and for hæmorrhoids is the use of high-frequency currents with the electrode applied over the affected area. In the case of piles a bare metal sound, introduced through the anus, is generally preferred.

294. **Exophthalmic Goitre.**—Quite a large literature has grown up on the electrical treatment of this disease, and many favourable cases have been recorded with various kinds of electrical treatment.

Cardew reported§ some cases in which the constant current produced great improvement in the symptoms. In nearly all of them the frequency of the pulse-rate was reduced, the enlargement of the thyroid was diminished, and the nervous condition of the patient was improved. He suggested that the treatment should be carried out by the patients themselves three times a day, and also at other times if the palpitation of the heart should become severe. He advised that a current of two to three milliampères should be applied for six minutes; the

* "Traitement des Maladies du Cœur par les Courants de haute Fréquence," J. B. Baillière, Paris, 1912.

† "Zur behandlung der Hertzkrankheiten," *Med. Klinik.*, 1906.

‡ "Traite pratique d' Électricite Médicale," 1910.

§ *Lancet*, July, 1891.

anode to the region of the lower cervical spine, the kathode to the side of the neck, from the mastoid process to the clavicle. He also showed that the diminished resistance of the body which has been observed in this disease is due simply to the increased perspiration and moisture of the skin, and this opinion is now generally accepted.

Induction-coil currents briskly applied to the neck have also been found efficacious.

Electrolysis of the enlarged thyroid gland has been recommended by Dr. G. Vaudey, of Marseilles.* The needles used for the electrolysis must be insulated where they pierce the skin, and he advises the insulation to be applied by the surgeon a short time before the operation, by dipping them into a solution of shellac in alcohol of 80 per cent. strength. The proportion of shellac to alcohol is as one part to five. Steel needles are used, and they are connected to the positive pole ; the end is left bare for the distance of one-fifth of an inch, in order that the electrolytic action may be localized in the actual thickness of the thyroid gland itself, and there is no electrolysis in the skin and superficial tissues. The use of varnish protects the skin from the risk of disfigurement by black marks due to oxide of iron deposited from the iron of the needle. Dr. Vaudey states that an anæsthetic is not necessary, and he reports several cases in which excellent results, both upon the general state of the patient and upon the enlarged gland itself, followed his treatment.

Many observers have used X rays with the object of producing more or less damage to the thyroid, on the view that the symptoms of Graves' disease are due to an excess of activity of the thyroid gland. In some cases it seems as if too much action had been produced by excessive X-ray treatment, so that patients have developed symptoms of myxœdema. Dr. Florence Stoney† has lately recorded 48 cases which she had treated by the X rays. She gives a dose twice a week for a month ; she then stops treatment for two weeks and then recommences. The dose given is less than a Sabouraud dose. Of the whole number treated 7 gave up attending before any results were obtained ; of the remaining 41, 14 were cured, 22 derived great benefit ; of the remaining 5, 1 died in Edinburgh after a surgical operation on the thyroid, and the others were unsuccessful for various reasons.

* *Annales d'Électrobiologie*, 1899, p. 182.

† *British Medical Journal*, August 31, 1912.

295. **The Respiratory Organs.**—Statical charging has been recommended as a valuable application for strengthening the singing voice. Moutier found that electrostatic applications had a favourable influence upon laryngeal fatigue (*fatigue vocale*). The method consisted in charging the patient, and in using a point electrode applied near to the nose and mouth. With daily applications lasting fifteen or twenty minutes, he noted an increase in the duration of the respiratory movements, the pitch of the laryngeal sounds was raised, and the sustained production of the higher notes was made more easy.

Electricity has also been used indirectly for the treatment of whooping-cough by ozonized air. The investigations of Bordier seem to show that the number of paroxysms of coughing may be notably diminished, and the duration of the illness shortened by administering an inhalation of ozonized air for ten minutes daily.

296. **Ozæna.**—Gautier, in 1892, advocated the treatment of this condition by electrolysis, or, as we should now term it, by "ionization" with copper. He made use of needles of the metal, which were inserted into the affected parts of the mucous membrane of the nose, usually of the middle turbinated bone. Currents of 15 to 30 milliampères are used for fifteen minutes or longer, the parts being well cocainized beforehand. Another method is to use copper rods covered with moist material wet with a solution of copper sulphate, and to apply somewhat similar strengths of current. The results are stated by several observers to be quite satisfactory. High-frequency currents have also proved successful; they are applied by slender vacuum electrodes, and act by the fine effluve and spark discharges.

297. **Asthma.**—Of electrical methods for the treatment of this condition, the use of statical applications is the best. Larat has recorded two cases in which immediate relief was afforded by static charging combined with sparks (roller electrode, § 127) to the whole thoracic region, and says that in one of his cases the patient remained well for three years, and in another one for two years after the termination of the treatment.

In asthma combined with emphysema there is usually arterial hypertension, and high-frequency treatment by autoconduction or the condenser couch is indicated. This often affords considerable relief in these cases.

298. **Pulmonary Tuberculosis.**—X rays are valuable in the early diagnosis of phthisis. The permanent records given by

X-ray photographs of the chest are of the greatest value for observing the progress of a case. The detection of small discrete masses of tubercle in the apex of a lung by X-ray photography is by no means difficult, and the possible error of confounding old and calcified masses with recent and active ones can best be overcome by examinations repeated at intervals of time. In examining the chest by the fluorescent screen it is observed that the movements of the diaphragm are much restricted on the affected side, and this symptom is thought to be one of the earliest morbid appearances to be observed in cases of commencing phthisis.

Dr. David Lawson, in a paper on the results of treatment in 301 cases of phthisis by open-air methods, states that at Banchory it has been customary always to screen and to skiagraph the patients soon after admission, after having previously formed an opinion by a careful physical examination of the conditions present, and it has frequently been his experience to detect by this means conditions which had not been even so much as suspected previously to the X rays being used. All chests were systematically examined by screening from time to time whilst patients were under treatment, and he had found observations so made on the subject of changes going on in the lesions a matter at once interesting, instructive, and helpful in the matter of treatment. The value claimed for the X rays in the treatment of tuberculous glands had been fully confirmed by the observations made in the few cases which had come under notice. One case of lupus of thirty-six years' standing had cleared up under its use, and at the time of writing, over twelve months since the treatment was suspended, appeared to be quite well. The X rays had also been applied in several cases of enlarged glands at the root of the lung. The results obtained in those cases, whilst not striking, have been at least encouraging.

H. Thiellé has done much careful experimental work on the treatment of phthisis by high-frequency, and his book is a monument of painstaking research. He takes the line that the respiratory exchanges are exaggerated in the tuberculous patient, either as a defensive reaction, as a consequence of the presence of the bacillus, or as a constitutional defect, whereas the gouty individual belongs to an opposite type, and, as has long been believed, has a constitution which strongly resists the tuber-

culous invasion. In order to treat a phthisical individual, therefore, one must endeavour to modify his respiratory exchanges, and to bring them to the normal values. Thiellé claims that by employing high-frequency currents this result can be more or less closely obtained, and the tendency to recovery goes hand in hand with the acquisition of normal characteristics (see also § 206).

299. **Pleural Adhesions.**—Leduc has advocated the treatment of pleural adhesions by the sclerolytic action of chlorine ions, and particularly in cases where scoliosis has come on as a sequel to severe pleurisy or empyema in children. He recommends the use of large electrodes to cover almost the whole affected side of the chest, with long and strong applications.

300. **The Mouth and Teeth.**—In dentistry ionization has been used for the sterilization of the roots of teeth. E. Zierler* claims that by these means the roots of septic teeth may be effectually sterilized at one short sitting. The current required is not more than 1 to 3 milliampères. A platino-iridium needle is attached to the positive pole, and the negative terminates in a plate applied to any convenient spot, the needle being passed as far up the root as possible. Salt solution is introduced into the root canal, and after the passage of a 3-milliampère current for ten minutes, the needle when withdrawn is found to be sterile, as is also the wall of the root canal; other portions of the root, and especially its exterior, may remain septic, but in practice it is seldom that the septicity of a root extends much beyond its canal and the soft parts immediately about its apex. Some patients cannot tolerate this amount of current, but the same results may be attained by a proportionately longer application of a weaker current. Sturridge† has confirmed the value of this procedure but uses zinc chloride of 3 per cent. strength and 3 or 4 milliampères. In pyorrhœa ionization has also proved successful in the hands of the same experimenter, who writes quite confidently about the value of the method, and prefers zinc ions for the purpose. He also records successes in the similar treatment of chronic alveolar abscess with fistulous openings on the gum, and has used both zinc and copper with good results.

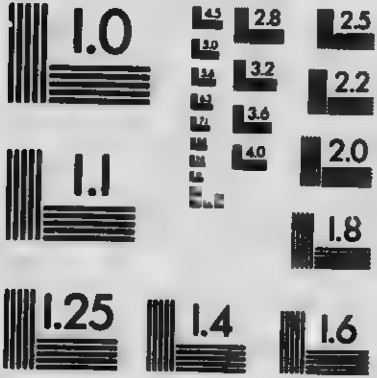
Occasionally cases are seen with troublesome ulceration inside

* "Behandlung putrider Zahnwurzeln," Würzburg, 1905.

† Proceedings Royal Society Medicine, 1912 (Odontological Section), p. 102.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



the nostril, on the tongue, or of the inside of the cheek. These may be rapidly cured by ionization either with zinc or coppe'.

301. **Œsophageal Spasm.**—Under the name of "œsophagism," Bordier defines this condition as a neurosis characterized by muscular spasm of the œsophagus, causing difficulty in swallowing. Cases of this class who have troublesome dysphagia, but in whom the passage of a sound proves that no organic stricture is present, are not very common, but are seen from time to time. A patient of mine, a gentleman of middle age, was very much inconvenienced by this form of spasm. He complained that he was prevented from entertaining his friends at dinner because of the difficulty which he experienced in swallowing; even when taking a meal quietly at home with his family, he was much embarrassed by the same trouble. Pain was also felt, and was referred sometimes to the epigastric region and sometimes to the sternum.

On several different occasions a short course of treatment by positive static charging, with brush discharge to the neck, chest, and epigast.ium, has dispelled the tendency to spasm, and has enabled him to eat with facility and comfort, the improvement lasting for several months after the suspension of treatment.

Bordier recommends the treatment of this neurosis either by direct or by induction-coil currents, applied externally to the neck and chest, and in more obstinate cases would apply currents directly to the œsophageal walls by means of a metallic bougie. In cases where a simple static treatment is successful these procedures will hardly be required.

302. **Stricture of the Œsophagus.**—Electrolysis has been recommended for stricture of the œsophagus by most writers on medical electricity. A bougie electrode is used connected to the negative pole of the battery. A bougie is selected of a size rather larger than the stricture, to which it is applied firmly. A current of five or ten milliampères is passed. After a variable time the stricture gives way, and the bougie passes through it. The time of each operation may be from ten minutes to half an hour. The operation is repeated with a larger instrument in ten days or a fortnight. No anæsthetic is required.

T. D. Savill* recently showed before the Clinical Society a case of traumatic stricture of the œsophagus relieved by electrolysis The patient, a woman aged forty-nine years, in the year

* *Lancet*, May 6, 1905.

1880 swallowed some vitriol by mistake. This was followed by extreme dysphagia and stricture, so that two years later a small bougie could only be passed with difficulty. After a time the difficulty in passing the bougie increased, and when the patient was seen in June, 1903, no bougie had been passed, nor had she swallowed solids for nine weeks, and fluids could only be swallowed with the greatest difficulty. Electric treatment was applied, and was quickly followed by improvement; in six weeks she could swallow minced meat, and had gained seven pounds in weight. The improvement was maintained for eighteen months, when a relapse required a renewal of the electricity, and she could now take solids without having to pass a bougie.

Radium has been used in the treatment of cancer of the œsophagus by Max Einhorn* and others. The method is as follows: An œsophageal tube is provided with a capsule made of metal. This capsule contains the radium. The tube is passed until the stricture is reached, and allowed to remain in the gullet for half to one hour or longer. The immediate results of the treatment in seven cases recorded by Einhorn were satisfactory. One patient, aged seventy-five years, had an obstruction 15 inches from the teeth, and could not even swallow fluids. He was treated for two and a half months, every other day for half an hour. His condition improved during the treatment, and at the end of it he could swallow fluid and semi-solid diet; five months later he was still improved, and suffered no pain. The second case was somewhat improved as far as the passage of the bougie was concerned, and felt a little better in herself; the third case lost all pain, felt considerably better, and could swallow more easily—a larger bougie could be passed; the fourth case was objectively much improved, the bougie could be passed without obstruction into the stomach, and she could swallow fluid and some solid food; the fifth case was also much improved objectively, and also as far as swallowing was concerned; the sixth case was gaining in weight, could swallow solid food well, and the stricture had disappeared; and lastly, the seventh case was practically uninfluenced by the treatment. In the last six cases the treatment was carried out for one hour each day. It is doubtful whether any permanently good results have been obtained.

* *Berliner klinische Wochenschrift*, No. 44A, 1905.

303. **Affections of the Stomach and Intestines.**—Electrical treatment is useful in certain affections of the gastro-intestinal tract. Herschell,* states that a cure can be obtained in certain forms of dyspepsia associated with neurasthenic states, that hyperæsthesia of the gastric mucous membrane can be diminished, gastralgia and gastric myasthenia relieved or cured, and that constipation depending upon intestinal atony can be remedied.

High-frequency currents are of service in cases of atonic dilatation of the stomach, the electrode being applied to the epigastrium.

304. **Constipation.**—Intestinal peristalsis can be set up by electrical currents applied through the abdominal walls, and chronic constipation can be permanently relieved by their use. The poles may be placed, one on the lumbar spine and the other on the surface of the abdomen; they should be of large size. The abdominal electrode should be moved over the whole surface of the belly for a period of five or ten minutes. After a few applications the bowels become more regular. Wahltuch† has reported seven cases in which the continuous current produced good results. His method was to use a large sponge for the positive pole, and an ordinary medium-sized one for the negative. The former was applied to the epigastrium, while the latter was slowly moved over the whole abdominal surface, in the direction of the intestinal canal from the duodenum to the sigmoid flexure, where it was finally fixed, and the current allowed to pass steadily without interruption for ten, twenty, or thirty minutes. The operation was repeated every other day for periods of from three to six weeks. The bowels gradually became regular in their action, although all aperients and enemata were stopped, and they remained so after the cessation of the treatment.

Many other writers have reported similar results, and I have myself obtained notably good results in some cases, though not in all.

Another plan which has been proposed for obstinate cases

* "A Manual of Intragastric Technique," H. J. Glaisher, London, 1903. "Practical Lessons in the Treatment of Affections of the Gastro-Intestinal Tract by Electrical Methods." "Medical Electrology and Radiology," A. Siegle, London, 1904.

† *British Medical Journal*, 1883, vol. ii., p. 623.

is to introduce a bougie electrode (Fig. 168) into the rectum, the other pole being kept on the abdomen as before; and to avoid the risk of electrolysis and injury to the rectal mucous membrane, a combined douche and electrode has been devised, and in France a number of cases have been treated for obstinate constipation in this way with success. It has even been used for cases described as intestinal obstruction. It is obvious, however, that the nature of the intestinal obstruction should be fairly well made out before undertaking to treat it by electricity.

Herschell recommends the use of three-phase currents (§ 90) for the treatment of constipation due to atony of the walls of the rectum, and enumerates several arrangements of the three electrodes. In one plan two are placed upon the back, one along each side of the vertebral column, and the third is applied to the epigastrium. In another, a rectal electrode is used, and consists of a bag of membrane surrounding a metallic tube which

FIG. 168.—RECTAL DOUCHE ELECT[illegible]E.

acts as conductor and also permits of the filling of the membrane bag with water after it has been introduced into the rectum. The second electrode is placed beneath the back, and the third is moved over the abdominal surface. The use of a membranous bag containing fluid in place of a continuous douche presents obvious advantages, as has been pointed out by Dr. Herschell.

Laquerrière and Delherm have made a careful study of the electric treatment of constipation which is worthy of attention.*

305. **Mucous Colitis.**—This affection is sometimes very notably benefited by general electrization, and the electric bath with sinusoidal current may be tried with advantage. Doumer has foun[illegible] [illegible]t direct current applied to the abdomen by means of two [illegible] electrodes placed in the iliac fossæ has proved valuable [illegible] relieving the constipation associated with this con-

* "Études cliniques sur les Traitements Electriques de la Constipation et de la Colite Muco-Membraneuse," *Annales d'Électrobiologie*, 1903.

dition. Currents from 30 milliampères upwards are used, and reversals are made every minute, the whole time of the application lasting eight or ten minutes.

Laquerrière and Delherm have confirmed Doumer's observations, and consider the results obtained to be brilliant. They report twenty-two successful results out of twenty-five cases treated.

J. C. Webb* has advocated the use of ionization with enemata of silver nitrate in colitis, and has reported cases in which the treatment was followed by good results. After a preliminary lavage of the bowel, one and a half pints of a silver nitrate solution of 0·1 per cent. strength were injected through a rectal tube, in which was a copper wire that could be connected to the positive pole of the battery. Large electrodes were placed on the back and abdomen and connected with the negative pole. A current of from fifteen to twenty milliampères was passed for fifteen minutes. The result of this treatment was that the motions became natural in consistency and frequency, that the mucus disappeared and the flatus diminished. He considered that there was an introduction of the ions of silver into the cells of the mucous membrane, and attributes his success in part to their influence.

306. **Affections of the Rectum.**—Electricity has been employed in various morbid conditions of the rectum and anus. In paretic states of the sphincter and in prolapse the application of induction-coil currents has been found useful by some writers, and the direct current has been applied with equal success by others.

In pruritus ani the static brush discharge, the effluve of the high-frequency apparatus, and the Röntgen rays are all efficacious methods of treatment.

In the treatment of some cases of piles, and of fissure of the anus, high-frequency applications are very successful. The method of application is to use a conical electrode of bare metal; this is anointed with vaseline and introduced into the anus, and daily applications of two or three minutes' duration are given. The patient should lie on the condenser couch (§ 133). In the case of piles the results appear to have been least satisfactory when the state has become chronic, with well-marked structural changes in the mucous membrane.

* *Lancet*, November 4, 1905.

In the case of rectal fissure the same electrode as that employed in piles may also be used, or one of the glass vacuum electrodes figured on p. 216. In either case they should be of sufficient diameter to stretch the folds of mucous membrane, in order that the effluve or current may touch the fissure itself.

Wallis and Bruce* have recorded five cases of ulceration of the rectum successfully treated by zinc ionization. They used a zinc electrode 6 inches long, covered with four layers of lint saturated with zinc sulphate solution of 4 per cent. strength. This was introduced so as to reach to the top of the ulcerated part, and a current of 20 to 30 milliampères was used for ten minutes. In other cases the bowel was closed above the affected region by an inflated rubber bag, and the rectum was then filled with the zinc solution. A zinc tube was used for distending the rubber bag, and to act as the electrode. The sphincter was protected with a collar of vulcanite.

Piles may also be treated by ionization, using a zinc needle. Bokenham† has recorded twenty cases treated in this manner, with currents ranging between 10 and 25 milliampères, and for ten minutes or longer, until the pile appears to have undergone coagulation. He uses several zinc needles in different parts of the tumour, and considers that they should be amalgamated, but not so much as to render the points brittle. If the pile is as large as a "pigeon's egg" it is done in two instalments, and if larger, in three, with intervals of ten days between. By the use of an injection of adrenalin and cocaine pain and bleeding are reduced.

Rectal fistula has also been successfully treated by zinc ionization. Billinkin‡ has recorded two cases. He says that after several unsuccessful attempts to cure this troublesome condition by ionization he had at last succeeded in securing a permanent result by using zinc. In his earlier cases the ionization had not been without result, but the fistula had not completely closed. In the first successful case the external opening was 3·5 centimetres from the anus, and the internal opening was 6 centimetres above the anal orifice. A slender zinc rod was introduced, its point being insulated by being covered with melted wax, which was allowed to harden. The index-finger in the

* Proceedings Royal Society Medicine, vol. i. (Surgery), p. 176.

† *Ibid.*, vol. ii. (Electrotherapeutic), p. 135.

‡ *Bulletin Officiel de la Société Française d'Électrotherapie*, June, 1906.

rectum could feel the insulated projecting portion, and serve to prevent it from penetrating too far into the rectal cavity. Six milliampères were used for three minutes, and the application was repeated two days later for three minutes with 5 milliampères, the electrode being introduced less deeply, and again three days afterwards, using a still shorter length of bare metal electrode. Two days afterwards the internal opening had closed, as was proved on trial by injecting some water, which did not reach the bowel. After this some further applications were made with the electrode shortened on each occasion. In all twenty applications were required. The place then healed soundly, and there remained a tiny depressed scar at the point where the external opening had been. In a second case, in a woman aged forty, there was a fistula 4 centimetres long, without any communication with the bowel. After six applications of zinc ionization at intervals of four days, each of three milliampères and three minutes, the fistula was completely obliterated. Its site was marked by a thickened cord in the submucous tissue. He considers that by the use of zinc as the ionizing material good results may be obtained, at least in non-tuberculous subjects.

CHAPTER XV

AFFECTIONS OF THE URINARY AND REPRODUCTIVE ORGANS

Incontinence of urine—Urethral stricture—Orchitis—Enlargement of the Prostate — Gonorrhœa — Amenorrhœa — Dysmenorrhœa — Endometritis — Vaginitis — Uterine fibro-myoma — Ovarian neuralgia — The vomiting of pregnancy—Parturition—The mammary glands.

307. **The Urinary Organs.**—Incontinence of urine is a symptom for which much can be done by electrical treatment. The cases of this complaint which are met with form several distinct groups. In one, there is want of tone in the sphincter of the bladder, and urine is expelled involuntarily during any muscular effort which involves the action of the abdominal muscles. In another group of cases occurring in women there is irritability of the bladder, and this discharges its contents with pain and spasm at frequent intervals, while in a third well-known form of incontinence the muscular apparatus is normal, but the bladder empties itself spontaneously during sleep.

In women it is not uncommon for there to be some inefficiency of the former kind, and in consequence a little urine is apt to be expelled from the bladder during muscular effort such as lifting a weight or during coughing or sneezing. If the weakness of the sphincter be rather more pronounced the incontinence becomes troublesome, and advice may be sought. The weakness of the sphincter may be due to parturition or to some dilatation or injury of the urethra—for example, after a digital examination of the bladder. The tone and power of the female urethra can be strengthened by electrical applications, and the patient's comfort may in this way be greatly increased. I have notes of several patients who suffered from incontinence of this kind, for which they were obliged in the daytime to wear a urinal apparatus, and were always wet and uncomfortable, and in whom a course of electrical treatment was completely suc-

cessful. In one instance, the incontinence was the result of an operation upon the urethra for the removal of a caruncle. Since the operation the patient had been unable to hold her water, which escaped during any muscular exertion. After four or five weeks' treatment she was able to lift and carry her baby, and to play tennis, without any leakage from the bladder. Other cases of weak sphincter in which electrical applications have given great relief are those in which the trouble has come on after childbirth, and as the result of a long railway journey without any opportunity of passing urine.

Even when the incontinence is part of a paraplegic condition treatment applied to the bladder may be of service. I have notes of two women who received injuries to the spine through jumping out of windows. They were referred to me for electrical treatment for their incontinence, and in both the power of the bladder seemed to be improved by treatment. Bladder weakness in tabes sometimes undergoes decided, if temporary, improvement from electrical applications to the lower spine and perineum.

The condition of irritability of bladder which produces frequent calls to micturate is one that is commonly confounded with nocturnal incontinence.

It seems to be associated with chronic cystitis, and careful questioning will reveal the fact that there is not only a tendency to wet the bed at night, but also a weakness by day. These cases occur almost exclusively in females. When up and about they are unable to retain their urine with comfort for more than half an hour or an hour. If after the lapse of that time they have no opportunity of emptying the bladder voluntarily, pain and spasm come on and the urine is expelled. At night, too, they are obliged either to get up frequently, or else to wet the bed. In hospital out-patient practice patients of this type are usually in a wet condition locally, and their clothing smells of urine, whereas true cases of nocturnal incontinence are not so.

No electrical treatment seems to have the slightest good effect upon the cases just described, and it is therefore very important before giving a prognosis to distinguish them from cases of true nocturnal incontinence, in which electrical treatment answers admirably.

308. **Nocturnal Incontinence.** — This affection has a totally different pathology to that of the kind of incontinence already

discussed. In nocturnal incontinence the patients are able to retain their urine in a perfectly natural manner so long as they are awake, but when asleep the bladder has a tendency to empty itself without awaking them. The condition is due to a persistence of the infantile mechanism of micturition, and the bladder acts during sleep in an automatic way, the controlling centre in the brain not being strong enough to maintain its action during the condition of sleep. The education of a child includes the education of inhibitory centres which bring the reflex mechanisms of micturition under the influence of the will, so that the action of the bladder in adult life is continually controlled. If the control be imperfect the bladder may empty itself whenever the higher centres are in abeyance, as during sleep. If sleep passes into coma, the controlling centre falls into abeyance in any case. A person suffering from nocturnal incontinence may pass water unconsciously in the daytime when asleep in a chair. As a rule sleep is very sound in patients who are the subjects of enuresis nocturna.

Electricity is of use in enuresis nocturna because it is able to stimulate the centres, both cerebral and spinal, by producing painful local impressions which tend in time to bring the inhibitory cerebral mechanism into more close r[illegible]on with the reflex centres in the lumbar cord.

It is important to try to combat the tendency to very deep sleep which exists in many of these patients. This may be attempted in various ways; for example, the number of the bedclothes should be reduced so that the patients are a little chilly at night; and a clock which strikes the hours is also a useful thing to have in the bedroom, especially if the patient can be taught to awake when the clock strikes twelve or any other hour which may be specified. They must be taught to practise retaining the urine as long as possible by day, so as to accustom the bladder to become more tolerant of its contents, and to augment the influence of the inhibitory centres by this exercise of their functions.

In children with enuresis nocturna it is important to search for any reflex irritation, and to remove it when possible. Thus worms, oxaluria, a narrow meatus, or phimosis, if present, must be dealt with before resorting to electrical treatment.

The results of treating nocturnal incontinence by electrical applications are very good. Most of the cases can be cured by attention to the points just enumerated.

The best mode of application for cases of incontinence with weakness of the sphincter in female patients is to introduce a bare metal sound into the urethra as one electrode, and to place the indifferent electrode upon the lower dorsal region of the back. The sound must not enter the bladder for more than a very short distance, otherwise but little current will pass to the walls of the urethra.

For male patients applications to the perineum will usually answer almost as well as the passage of a sound, and the latter, which is too painful for use with children, may, therefore, be reserved for the more troublesome cases; the use of a perineal electrode makes the operative procedure more simple and less formidable to the patient. An electrode of suitable shape consists of an acorn-shaped piece of metal fitted with a handle, and it is so contrived that a chamois-leather cover can be adapted to

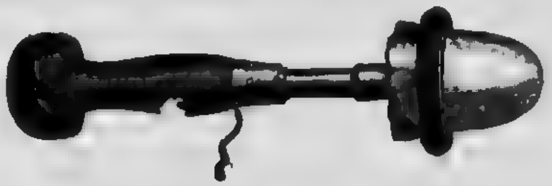


FIG. 169.—ELECTRODE FOR ENURESIS.

it in a moment for each application. A ring of vulcanite pushed on over the piece of leather serves to hold the latter in place (Fig. 169).

The currents used must be decidedly painful, in order to produce a suitable impression upon the nerve centres. It is useless to undertake the electrical treatment of incontinence without direct applications to the perineal region, and consequently it is important not to allow incontinence of urine in children to be left untreated in the hope that they may outgrow it, because in girls after puberty the local applications may be a source of embarrassment.

In the treatment of incontinence of urine the induction coil applied rhythmically for eight minutes, and followed by a battery current of five to ten milliampères with reversals every five seconds for three or four minutes, seems to give the best results. The reversals are used to avoid the risk of injuring the skin and mucous membrane through electrolytic action.

309. **Atony of the Bladder.**—This symptom may be due to enlarged prostate, to lesions of the lumbar and sacral cord, or it

may follow the enforced retention of urine for a long time, as, for instance, during a long railway journey. The treatment will depend upon the nature of the case. When there is prostatic enlargement this must be dealt with. The case of the paralytic affections has already been referred to in § 307. The third group of cases, which are rarely met with, may be treated by the introduction of a bougie electrode, and the daily application of rhythmic faradic or galvanic currents. In using the latter it is prudent to employ reversals of current, in order to reduce to a minimum the risk of injury to the bladder wall by electrolytic action. For the same reason the applications should be made on a full rather than with an empty bladder. I have seen good results follow.

310. **Stricture of the Urethra.**—Modern writers on this subject refer to Crussel, 1839, as the first to use electrolysis for the cure of this condition, and to Mallez and Tripier* as the first to practise it systematically.

The electrical treatment of any disease, in order to justify its existence, must offer results which are superior to those which can be had in other ways, and apparently surgeons do not find it necessary to use electrolysis in stricture of the urethra because they can obtain the required results without it.

Steavenson, in 1886, gave an account of electrolysis in stricture and stated that for the treatment of stricture of the urethra, the electrodes are to have the form of catheter-shaped gum-elastic bougies, ending in a metal nickel-plated piece connected to a binding-screw on the handle.

An ordinary bougie is first passed down to the stricture, and by its means the distance of the stricture from the meatus is ascertained, and a mark made on the bougie. It is then found out what sized bougie will pass the stricture. Say, for instance, it is ascertained that a No. 3 bougie (English) will pass; a No. 5 electrode is then taken and passed down to the stricture, where it is arrested. It can be made certain that the electrode is arrested at the stricture by previously marking it, after measurement and comparison with the bougie first passed. When the electrode is in position against the stricture, it is connected with the negative pole of the battery, the circuit is closed, and the

* "De la Guérison durable des Rétrécissements de l'Uréthre par la Galvano-caustique Chimique," Paris, 1867.

current gradually increased without breaks until the maximum strength is reached that it is intended to employ—namely, about five or six milliampères. The electrode is kept gently pressed against the stricture in the direction of the ordinary course of the urethra. By the dissolution of the obstacle in front of it, the electrode slowly passes into the bladder. The current then should immediately be cut off and the bougie withdrawn. The result of the operation depends, in all probability, upon the sclerolytic action of the chlorine ions.

The subject of electrolysis for urethral stricture still receives a certain amount of attention from individual operators.

311. **Orchitis.**—Scharff* claims to have employed electricity successfully in the treatment of epididymitis. He does not wait until the affection has become chronic, but immediately and during the acute stage applies the anode to the lower part of the scrotum. The patient being in the dorsal position, a large electrode is employed, the duration of the application being three minutes on the first occasion ; this is afterwards increased to five and ten minutes, the increase being very gradual. A weak constant current is employed at first. No unpleasant sensation should be thus produced, but the patient will subsequently on palpation be able to observe a considerable diminution or total disappearance of the tenderness which had previously existed. While in the same position a suitable suspender is applied, and the patient then allowed to walk about. Towards the seventh day the current can be increased. The kathode is placed above the groin and on the abdominal wall. Onimus also speaks very favourably of the good effect of electrical treatment in orchitis, and Picot, of Tours, has reported good results in forty cases ; both used currents of about five milliampères.

Dr. Duboc,† of Rouen, has reported two cases of chronic orchitis and epididymitis following gonorrhœa treated successfully by electricity ; one had lasted for eighteen months in spite of much medication, the other for nine months. In both cases the swellings disappeared rapidly and completely after about six applications. Two pads were used, one in front of the testicle, and one behind ; both were moistened with a twenty per cent solution of iodide of potassium and a continuous current of twenty milliampères was used for ten minutes.

* *Centralbl. f. Krankh. d. Harn. und Sex. Organe*, 1, 1894.

† *Archives d'Électricité Médicale*, 1894.

312. **Prostatic Enlargement.**—X rays have been successfully used in this disorder. Caracelli and Lucaselli* report two cases of enlarged prostate in men over sixty which were much improved by X-ray treatment. The improvement was, moreover, maintained when the patients were seen a year later. The *modus operandi* was to place the patients in a suitable position, protecting the scrotum, penis, and thighs by means of a lead plate, and then to apply the rays to the perineum at twenty to twenty-five centimetres distance for about ten minutes at a time for two and three times a week, then every fortnight. Under this treatment the urine cleared, the flow of urine was improved, and the frequency of micturition lessened. The authors consider it unnecessary to use a speculum in the rectum, as the rays act equally well when applied externally in the method adopted by them.

Moszkowitz also has used X rays for enlarged prostate. Of three men who were treated, the first was sixty-six years old, and after three exposures, each lasting fifteen minutes, he was able to pass urine spontaneously. The second patient was seventy-seven years old, and his prostate was enormously enlarged and very hard. The same treatment was adopted, with the result that he could pass urine freely, though some of it was still retained. The third patient was completely cured. Two of them had severe hæmorrhagic cystitis, and one had epididymitis after seventeen days. It was difficult to say whether these complications were the effects of the rays. As regards the technique, a rectal speculum was used, and the surrounding parts were covered by lead.

Léron† has reviewed the literature of the Röntgen-ray treatment of hypertrophy of the prostate, and finds that in general it shows very favourable results.

Guillemonat‡ has recorded an interesting case in a man of sixty-five. He passed urine about twenty-five times a day, and had been treated with high-frequency currents without success. Applications were given for five minutes every other day, as the patient could not keep still for a longer time. After five applications improvement began, and the patient passed urine less often, and after twenty applications his micturition was effected twelve

* *Gazz. degli Osp.*, January 18, 1905.
† *La Clinique*, April 13, 1906.
‡ *Annales d'Électrobiologie*, February, 1907.

times in the twenty-four hours. Treatment was then stopped for a time, and renewed later. In the end the patient could pass the whole night without urinating, and his prostate was much reduced, although still showing some degree of hypertrophy.

High frequency applications, with a metal intrarectal electrode, will also relieve congestion in these cases, and in that way may reduce the symptoms to a useful degree.

313. **Varicocele.**—The pain is said to be relieved by applications of direct current if the scrotum is immersed in a small bowl of warm water connected to the positive pole ; the negative pole is applied to the inguinal region or over the sacrum. The vasomotor effects of applications of high frequency also answer very well. The patient lies on the condenser couch, and the electrode is carefully adapted to the scrotum with the aid of a folded cloth, or of Gamgee tissue moistened with salt solution.

314. **Sexual Debility.**—For impotence and sexual debility Erb has advised that a small button-shaped electrode connected with the positive pole be held to the perineum, and another larger electrode (negative) be moved slowly up and down the lower dorsal and lumbar spine. The current may be of from five to ten milliampères, according to the tolerance of the patient, and the time occupied may be ten minutes. Applications daily for a week, then every other day. In this way the symptoms may be dispelled. Faradization of the scrotum with a brush electrode is also useful, and the patient can do it for himself. Several of my patients have found this procedure valuable. If the blood-pressure is depressed, statical treatment may prove useful.

Impotence is often largely mental, and aggravated by the consciousness of past failures. Patients must be instructed to make no attempts at connection until they feel confident of success.

315. **Gonorrhœa.**—This condition has been successfully treated by ionization. W. J. Morton* recorded a case as early as 1895, in which zinc and copper ions were used. A brass bulb connected to an insulated stem was introduced as far as the neck of the bladder, the current turned on, and the bulb slowly withdrawn, so that it might act in turn upon the whole length of the urethra. Two days later the discharge had entirely ceased.

A year later the same patient again contracted gonorrhœa, and

* "Electric Medicamental Diffusion," *The Journal of the American Medical Association*, May 4, 1895.

was treated in the same way. With a copper bulb four milliampères of current were given. The discharge was almost entirely stopped, but the treatment was repeated ten days later, and there was no further trouble.

P. C. Fenwick* has recorded two cures of chronic urethritis by zinc ionization. A zinc rod wrapped with fine lint, and wetted with 2 per cent. zinc sulphate, was introduced through a cannula into the urethra, and the cannula then withdrawn. The urethra was cleaned with swabs beforehand, and two milliampères of current were used. In one case a discharge which had lasted for two years disappeared after three applications, and in the second case five milliampères were used, and a result obtained after five applications, the disease having lasted a year.

MacMunn has recommended the use of a zinc rod enclosed in a catheter, which it fits loosely. Holes are cut at intervals in the catheter, and the zinc solution slowly caused to flow in from its end. It escapes through the holes, and conveys the current to the walls of the urethra.

316. **Diseases of Women.**—Electrical methods are made use of in gynæcological practice, not only for their direct effects, but also for electrolysis, and the galvano-cautery. Much progress has been made in the treatment of the numerous and troublesome septic conditions of the female genital tract by the applications of ionic indication, which here find a very suitable field of application.

The use of electricity in diseases of women is so much a matter for the gynæcologist himself that a few brief notices of the different conditions in which electricity can be simply applied will suffice in the present work. Readers who are interested should consult the writings of Dr. Samuel Sloan,† who has contributed much to the practical side of ionic treatment in gynæcology, and in the last-mentioned paper has tabulated the notes of 153 cases treated by various electrical methods. Curtis Webb‡ has also written an interesting account of his experience in gynæcological therapeutics.

* *British Medical Journa'*, August 15, 1908.

† "The Electro-Chemical (Ionic) Treatment of Certain Gynæcological Affections," *Lancet*, December 23, 1911; "Electro-Therapeutics in Gynæcology," Proceedings of the Royal Society of Medicine (Electrotherapeutic Section), October, 1909.

‡ Proceedings of the Royal Society of Medicine (Obstetrical Section), 1909.

317. **Amenorrhœa.**—Electricity has been employed in the treatment of this condition for a long time. Golding Bird* had a very high opinion of the value of shocks from the Leyden jar for curing this symptom, and writes at some length upon it in his little book. His method was to transmit through the pelvis twelve shocks in succession from a small Leyden jar, the discharge being directed from the sacrum to the pubes. The treatment by positive charging with the static machine, combined with the breeze (§ 125) to the back and loins is also quite useful in certain cases. Recently I was asked to see a young lady whose periods were irregular; the catamenia had been absent for three or four months. She was not particularly anæmic but had been keeping late hours, and was run down. I gave her an application of the kind just described, and arranged that she should attend for a regular course of treatment. A period commenced within a few hours of the application, so that she did not return for further treatment. Two months later, having again missed a period, she came again, and again a single static application brought on a comfortable period, since when she has remained quite regular. In § 188 some observations on the effect of static applications in menstrual irregularities has been mentioned.

The electric bath by its effect on nutrition acts as an indirect emmenagogue in chlorosis.

In healthy women in whom menstruation is regularly performed, electricity may certainly hasten the appearance of the flow, especially when it is applied to the abdomen or pelvic region. The electric bath may have the same effect.

It is best to suspend general electrical treatment in women for a few days before the menstrual periods, otherwise the flow may be rendered excessive, and in pregnancy it is better not to make applications of electricity to the abdomen or pelvis.

318. **Dysmenorrhœa.**—The effect on painful menstruation of the statical breeze has been referred to in § 188. It is a mode of treatment which gives good results in many cases, the patient being charged positively with the negative breeze to the loins and spine. It should be given daily for a week or two before the date of the appearance of the menstrual flow, and the applications should be of twenty minutes duration. When the flow has com-

* Golding Bird, "Electricity and Magnetism," 1849, Lecture V., and Appendix B.

menced, the applications may be suspended until the corresponding time before the next period, and then resumed as before.

Curtis Webb speaks well of the wave current (§ 124), applied with a bare metal sound within the rectum or the uterus. Sloan finds simple applications of high frequency sufficient in simple cases, without any local treatment. Associated conditions of the pelvic organs must be dealt with, if necessary.

319. **Endometritis.**—Sloan tells us that in septic conditions of the endometrium ionization with zinc is of great value, and that he finds it more useful than the use of the curette. Of twenty-six cases treated by ionization, twenty-five were successful, and only one was not benefited. Several of these had previously been treated by curetting without success. The usual method is the

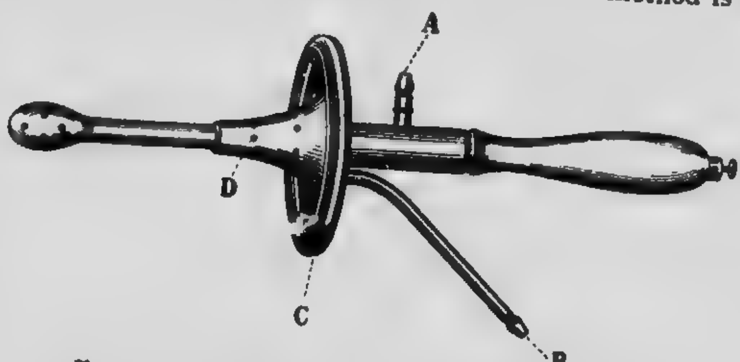


FIG. 170.—CLEAVES' VAGINAL DOUCHE ELECTRODE.
A, Inlet; *B*, outlet; *C*, collar of soft indiarubber; *D*, perforations for outflow.

use of a zinc sound, introduced into the uterus, and made the anode for a current of from twenty to forty milliampères for fifteen minutes. The vagina is douched for cleansing purposes before the application, and as there is a free discharge for several days after the ionization, the douching should be continued during that period.

Other writers have written reporting favourable results from similar treatment, and praising the method.

320. **Vaginitis.**—In vulvar and vaginal septic conditions a rod of zinc wrapped with lint or wool wetted with the zinc solution is employed, or a method of irrigation is combined with the current.

Dr. Margaret Cleaves* has advocated the use of a douche electrode like that shown in Fig. 170 for electric applications to

* *Medical Record*, August 25, 1894.

the female genital apparatus. By the addition of a soft rubber collar it can be made to enclose the external parts, and to act as a partially water-tight cap, thus permitting of slight distension of the mucous membrane, and a penetration of the fluid into its folds and interstices. She has found applications by means of this electrode to be valuable in the treatment of pelvic exudates (parametritis), ovaritis, vaginitis, eczema, and pruritus of the vulva, and prefers it to all other forms of electrode.

The external part of the electrode is of hard rubber, with a binding-screw and two tubes to act as inlet and outlet respectively. The shield *D* is movable, and has two rows of perforations through which the surplus water drains into the tube *B*. To this drainage-tube is affixed a few feet of rubber hose, of less diameter than that on the fountain syringe through which the water or the medicated solution gains entrance into the vagina, in order to retard the drainage and keep the vagina distended during the time of administration of the current. This drainage-hose is dropped into a jar at the foot of the operating-table, the syringe-hose is attached at *A*, and the vagina allowed to become well distended with the water or medicated solution before the current is turned on. By firm and even pressure of the shield over the ostium vaginæ, with the labia folded out, so as to occasion no discomfort to the patient, it is possible to administer any quantity of the douche (1 to 3 or more quarts) without getting a drop upon the patient's clothing.

A cushion of soft rubber is placed over the edge of the shield, as will be seen at *C*. This renders it possible to maintain distension of the vagina by shutting off the outlet-tube by means of a clamp. The surplus water, however, that remains with continuous drainage is enough to penetrate every fold and ruga of the vaginal mucous membrane, as may be demonstrated by cutting off the inflow and taking note of the amount remaining as it drains away.

The conducting end of the electrode may consist of a carbon tube or one of zinc or copper enclosed in the vulcanite cover. In gonorrhœal vaginitis it is possible by this method to bring not only the os and cervix uteri, but every interstice of the vagina as well, under the influence of the medicated solution. The authoress, recognizing the principles of ionic medication at a time (1894) when they were very little appreciated, uses the following significant statement :

"The fact that the gonococcus penetrates the submucous structures makes it very desirable that we should be able to apply our remedies in such a manner as to insure their destruction. By cataphoric medication this is possible, as the medicament not only comes in contact with the mucous membrane, but is caused to penetrate more or less deeply into its structure according to the strength of the current and the length of the application.

"By means of anodal diffusion, a solution of sulphate of copper of requisite strength could be used to advantage in gonorrhœal cases. In the later stages of gonorrhœa, in conditions of pelvic congestion, uterine catarrh, and in some leucorrhœas, hydrastine thus diffused would be of much greater efficacy than administration by the mouth, or by means of vaginal injections. Bichloride of mercury in solution could also be used according to the indications, and in strength of 1 to 1,000."

321. **Parametritis.**—Cleaves has also insisted upon the utility of the same mode of treatment in parametric exudations. Sloan also mentions a number of cases in which pelvic inflammations were much improved by applications of ionization or of continuous current, the latter probably being active by setting up ionic interchanges in the congested and thickened areas.

322. **Uterine Fibroids.**—Formerly these were treated by Apostoli by applications of continuous current to the inside of the uterus with platinum sounds. Currents of sixty milliampères or more were used once or twice a week for periods of ten or fifteen minutes. The action was an electrolysis of the mucous membrane by the hydroxyl ions migrating inwards from the sound, which was made the negative pole, and by the caustic soda set free by secondary action. There was also an interstitial migration of ions within the substance of the uterus, which may have had some effect. The results were to reduce the size of the uterus and to decrease the hæmorrhage. The destruction of the mucous membrane is followed by a healthy process of repair, by a process of involution, and by a cicatrization which checks the metrorrhagia.

Bergonié and Boursier* have published the notes of a hundred cases in which they carried out Apostoli's treatment for fibromyoma, and they give the following summary of their views: "The electric treatment of fibro-myoma is undoubtedly efficacious as a palliative method of treatment. When hæmorrhage

* *Arch. d'Élect. Med.*, 1893, p. 211.

was the chief symptom complained of, 90 per cent. were relieved. The general state of health was improved in 79 per cent., the symptom of pain was relieved in 50 per cent., while a decrease in the size of the tumour was observed in 10 per cent. only."

Much was written on Apostoli's method, and most of the papers were collected and issued by Apostoli himself in the form of a book, which may be consulted by those interested in the history of the subject.

At the present time fibroids of the uterus are treated by the applications of X rays to the abdomen, the object being to damage the ovaries and to bring about artificially a premature menopause. In the Proceedings of the Royal Society of Medicine (Electrotherapeutic Section) for March 15, 1912, a paper by Bordier will be found which gives a detailed account of his method of procedure. He gives a series of nine irradiations on nine consecutive days, one on the right flank, one on the left, and one on the median line of the abdomen, repeating in the same order until each part has had three applications, making nine in all. All parts except that one receiving the irradiation are carefully shielded by a large sheet of opaque rubber material, and the part treated is done through a filter of aluminium. For the median region this is 3·5 millimetres in thickness; for the lateral regions he begins with a filter 0·5 millimetre in thickness, increased to 1·0 millimetre for the third irradiation. The series of nine applications is repeated a month later, when the aluminium filter is 0·5 millimetre for the first, 1·3 millimetres for the second, and 1·5 millimetres for the third set of lateral applications, but remains the same as at first—namely, 3·5 millimetres for the median line.

If necessary, a third series and a fourth series may be given after the lapse of one and of two more months, and even a fifth in the fifth intermenstrual interval, if it should be necessary. For these later series of irradiations the filtration for the lateral regions increases gradually. In the third series it is 1, 1·5, and 2 millimetres; in the fourth 2, 2·5, and 3 millimetres; and in the fifth 2·5, 3, and 3·5 millimetres.

The dose is determined by the pastilles of barium platinocyanide (§ 145), and is 5 H. (3·6 I.), or tint 3 on Bordier's scale. The pastille is placed on the filter, on the side facing the X-ray tube, and the amount received by the skin is therefore a fraction

of the quantity recorded by the pastille, and ranges from 55 per cent. with the thinnest filter to 12 per cent. for the thickest of those used for the lateral regions, which is the same as that used throughout for the median region.

Hard rays, 9 or 10 Benoist (§ 144), are to be employed; the distance from the antikathode to the skin is 16 centimetres. The filter is a hand's-breadth from the wall of the tube. The filters should be earthed to avoid any sparking to the patient.

A large literature has already grown up around the subject of the X-ray treatment of fibro-myoma. Bordier recommends that the treatment should be limited to persons past the age of thirty-nine. He thinks that interstitial fibro-myoma is the most amenable to the treatment, and that simple cases suffering chiefly from the symptom of hæmorrhage respond best.

323. **Ovarian Neuralgia.**—The abdominal pains felt by women and referred to a tender ovary may be treated by electricity. By some writers these pains are regarded as an expression of a general condition rather than as a sign of local disease, and on this ground the treatment advised is that of general electrization. Local treatment by direct current may also be employed successfully if large currents and long applications are used. Currents of 40 or 50 milliampères applied by means of large electrodes, placed one on the front of the abdomen and one at the corresponding part of the back, are recommended.

324. **The Vomiting of Pregnancy.**—Drs. Gautier and Larat* have described a series of cases, eleven in number, in which the use of direct current arrested obstinate vomiting of this kind. The positive pole should be applied above the clavicle between the attachments of the sterno-mastoid muscle, while the negative pole is placed at the epigastrium. The current should be of eight to ten milliampères turned on and off very gradually, and continued for fifteen minutes. It may be applied several times daily in severe cases. In from twenty-four to forty-eight hours from the first application the vomiting was either greatly alleviated or had ceased entirely. Bordier and Verney have also published favourable results obtained in this manner.

325. **In Parturition.**—In a paper read by Dr. Kilner before the Obstetrical Society,† the use of the induction-coil current is

* "Traitement par l'électricité des Vomissements Nerveux, et en particulière des Vomissements incoercibles de la Grossesse," Paris, 1895.

† *British Medical Journal*, April, 1884.

advocated during parturition as a means of provoking or of strengthening uterine contractions. Sometimes the resulting contractions were very severe and prolonged, indicating possible risk to the child. The applications seemed to diminish the pains felt during the labour, and after the birth of the child insured a firm uterine contraction, and much diminished the risk of post-partum hæmorrhage. Some medical men speak very highly of its value in childbirth, and make a practice of carrying a small induction coil in their obstetric bag. It has also been of service in flooding after miscarriage.

It follows that caution is necessary before applying electrical treatment to the abdomen or pelvic organs of a pregnant woman. An early writer speaks of having produced a miscarriage as the result of Leyden-jar shocks applied in this way.

P. Robecchi* has suggested the use of an electric sound for the induction of labour, or for stimulating the interior of the uterus, and he states that by suitably arranging the periods of stimulation and of rest it is possible to start uterine contractions of a rhythmic character which closely resemble those of a naturally contracting uterus.

X rays have been suggested as a means of inducing labour prematurely, but apparently they do not readily act in that way. H. E. Schmidt† has recorded a case in which they were tried for this purpose, but although a dermatitis was set up on the abdominal wall, the pregnancy was not interfered with.

326. **The Mammary Glands.**—Electrical stimulation applied to the mammary glands has been found useful for promoting the secretion of milk in nursing women.

Two patients who were suckling their infants were treated in this way in the Electrical Department at St. Bartholomew's Hospital for failure in their milk-producing powers. In one case a decided improvement followed. In the other the results were doubtful. It is not often that the advice of medical men is sought for producing an increase of the mammary secretion.

Successful cases are quoted by Drs. Beard and Rockwell, and by several recent French writers.

Electricity has also been recommended as a means of increasing the size of the breasts in cases where their development is defective.

* *Giorn. dell. R. Accad. di Med. di Torino*, December, 1903.

† *Deutsch. med. Wochenschrift*, June 17, 1909.

CHAPTER XVI

AFFECTIONS . THE JOINTS AND FIBROUS TISSUES

Injuries of joints—Stiffened joints—Gonorrhœal arthritis—Chronic gout—Rheumatoid arthritis—Chronic synovitis of knees—Tuberculous joints—Spondylitis deformans—Fibrositis.

327. **Injuries of Joints.**—Remak wrote much on the treatment of joint affections by continuous currents, and recently the use of ionization has strengthened our resources for the treatment of this class of case. Sprains of all kinds can be quickly relieved by applications of continuous current by the methods used for ionization, and should always be treated in this way when quick results are desired. The currents should be large and applied for twenty minutes or longer on alternate days in the chronic cases, and daily in the recent ones. Ammonium or sodium chloride should be used for the cloths used as electrodes. Both electrodes can be applied to the joint, one on each side of it, or the joint can be enveloped in the cloth constituting the kathode, and the anode applied at a little distance. The case quoted in § 286 from Remak may be used to show the effect in a recent severe sprain, and it will not be amiss to quote another of his cases, which Remak himself considered worthy to be recorded as marking an epoch in the history of the therapeutic effects of electrical currents. A tailor, aged thirty-six, fell down on a road slippery with ice, and injured his right wrist so much that he was unable to move it after the accident, or to close his fingers. He passed a sleepless night from pain in spite of the application of fomentations. When seen next day, the whole wrist was much swelled, and so painful that a detailed examination was hardly possible. The part was hot, the fingers stiff and swelled. No fracture could be detected. An application was made with thirty Daniell cells for five minutes, and during its course the patient felt some relief. On the following day the movements of the fingers had partly returned, so that

he could use his needle a little. A second application was made, and the next day the patient declared himself free from all inconvenience.

The following case of chronic joint injury is related by Leduc.* A girl of twenty-one was struck on the knee when dancing, and the pain was so great as to cause her to fall. She could not get up again, and was carried home. The next day there was a considerable synovial effusion and much pain. Blisters were applied, and the synovial effusion subsided in the course of some weeks. Pain, however, persisted, and walking was impossible. In spite of all kinds of treatment, she continued to suffer from the state of the joint for two years, when she was first seen by Leduc. She then had a stiff knee, and walked with two crutches. The circumference of the joint was one centimetre and a half greater than that of the other knee; the periarticular tissues and particularly the synovial membrane (or capsule) of the joint were thickened. Movements were possible, and were accompanied by fine crepitations. The muscles of the whole limb were wasted from disuse. Daily treatment was given with continuous and interrupted currents on alternate days, and in two months the patient could walk without crutches or a stick, and after a further treatment she was completely cured.

Danion† has recorded rapidly favourable results from the treatment of recent sprains by interrupted currents, and refers to Tripier as having related similar experiences.

The painful chronic sprains at the elbow-joint which are sometimes called "tennis elbow" respond well to ionization. Usually I have used salicylic ions, as the cases I have seen have occurred for the most part about middle life, and the possibility of an underlying gouty tendency could not be excluded. These cases, which remain almost uninfluenced by small currents, are soon relieved by large currents of twenty or thirty milliampères applied for twenty minutes. All massage and movements should be prohibited, as it is more than likely that some of these sprains become chronic through want of rest to the injured ligaments.

328. **Stiffened Joints.**—After various acute affections, one or more joints may be left stiff, either from fibrous changes within

* "Action Thérapeutique des Courants Continus," *Gazette Médicale de Nantes*, 1893.

† "Traitement des Affections Articulaires par l'Électricité," Paris, Octave Doin, 1887.

the joint, or from alterations around it. The stiff hands which follow serious whitlow are an instance of the condition referred to. These cases, though slow to respond can be very greatly ameliorated by electricity, and especially by ionic medication with chlorine ions; and it is probably to this "sclerolytic" action of the current that many cases reported in the past have owed the good results produced. Dr. Margaret Cleaves,* who early recognized the good effects of electrical treatment in such cases, has recorded two which were greatly benefited.

Leduc† has described the case of a young lady who developed phlebitis after typhoid fever. Following upon this there was a stiffening of the left knee-joint which was treated unsuccessfully in various ways for more than a year. At the end of that time the joint was ankylosed, immobile, and painful; it felt cold to the touch, and the tissues surrounding the joint were thickened and slightly œdematous. The patient could not walk nor bear on the limb with any weight. Electrical treatment was commenced. A large electrode (negative) was moulded to fit the region of the joint, the positive indifferent electrode being applied to the epigastrium, and a current of twenty milliampères was applied for ten minutes. Afterwards thirty and forty-five milliampères for fifteen minutes were employed. Improvement quickly began, and after twenty-two applications extending over two months the joint had become freely movable and the patient could stand and walk.

Other cases of the same kind are referred to, and the writer concludes by saying that the useful action of electricity in cases of joints stiffened by past inflammation is incontestable. A point of importance for success is that the treatment must only be applied to joints which are no longer the seat of inflammation. It is necessary to wait until all active mischief in the joint has subsided.

In another paper by Professor Leduc, seven cases are reported which afford valuable evidence of the advantages to be derived from applications of direct current to joints stiffened by old injury or past inflammation. One, a rheumatic case, in a gentleman aged forty-seven, was such that for two years the patient had to be dressed and carried from his bed to his couch by attendants.

* "The Continuous Current in Relation to Inflammatory Exudates." *Medical News*, New York, April 29, 1905.

† *Archives d'Électricité Médicale*, 1894, p. 478.

He could not stand up. After thirty applications during sixty days he could walk well enough to undertake a journey to Paris, and his improved condition was well maintained. The effect is doubtless to be attributed to the sclerolytic action of chlorine ions.

Desfosses and Martinet* state that in a number of cases in which joints had been left stiffened after injury, inflammations, or attacks of rheumatism, they had found ionization valuable. They advise applications of half an hour or an hour, and large currents. Salicylic and chlorine ions are both useful.

329. **Gonorrhœal Arthritis.**—This form of joint inflammation is relieved by ionization with salicylic ions in its acute stages. Billinkin† has recorded a case of this kind as follows: A commercial traveller aged twenty-four contracted a gonorrhœa, and ten days later his left wrist became swelled and tender. Five days later he was seen by Billinkin, who found great swelling of the wrist, which was painful and fixed. An application was at once made of salicylic ionization, 120 milliampères for fifteen minutes. The active electrode enveloped the whole wrist and three-quarters of the forearm. Treatment was repeated four times in the following five days, and on the last occasion the patient considered himself cured, and the pain and swelling had disappeared. He was seen again a week later, with a wrist free from pain, normal in appearance, and freely movable.

Laqueur‡ has recorded good effects in the subacute stages from diathermy, and Berndt § has hinted at the possibility of killing the gonococcus within the joint without damaging its structure, by means of the heating effect of the diathermal applications. He considers diathermy to be particularly indicated in all acute and recent cases of gonorrhœal arthritis.

In the stiff joints left after gonorrhœal arthritis ionization with chlorine ions is the best treatment. Many writers have reported cases of success after applications either of continuous current simply, or of ionization with chlorine ions. In either case the results are due to ionic displacements in the tissues of the joint. In a case under my own care, great progress was made during six weeks of treatment given to a knee-joint which had been left almost completely ankylosed. The applications

* *Presse Médicale*, 1907, No. 23.

† *Bulletin Officiel de l'Societé Française d'Électrothérapie*, June, 1905.

‡ *Zeitschrift für Physik. und Diät. Therapie*, 1909, p. 277.

§ *Ibid.*, p. 167.

were made twice a week, currents of sixty milliampères were used, and at the end of the course there was a great increase of mobility, and the improvement was still in progress. In another case in which the wrist was much ankylosed, a similar improvement was produced. Chlorine ions were used in both cases.

If there is any doubt as to whether the infective process has entirely ceased in an affected joint, probably the salicylic ion should be preferred; when one has to do simply with stiffness left after all gonorrhœal infection has passed away, then chlorine or iodine ions are better.

330. **Chronic Gouty Arthritis.**—Ionization produces good results in these cases. Salicylic ions appear to answer best. Applications may be made on alternate days, according to the usual methods of ionization. In the case of the extremities the treatment may be applied by means of baths, with a lithium salt at the positive and sodium salicylate at the negative pole (§ 201). Leduc has expressed the opinion that the use of cloths or cotton-tissue applied round the joint is better than immersion of the limb in a bath, as a more uniform penetration of the current occurs with the former method.

Many writers have reported good results, which I can confirm from my own experience.

Michaut* has advised the use of thyminic acid, and states that by its introduction as an ion with currents of fifteen milliampères during forty minutes, he has seen a tophus disappear in a short time. The salt used was the sodium thyminate. Thyminic acid or nucleotin-phosphoric acid is a product of tissue metabolism, and is formed from the nucleo-proteids. It has a solvent action on uric acid, and it has been said that the precipitation of urates in the body is a result of the lack of thyminic acid. It has been administered internally in doses of 5 grains.

331. **Rheumatoid Arthritis.**—In view of the belief, which is steadily gaining ground, that all the chronic joint affections known by this name and by that of osteo-arthritis are manifestations of obscure septic absorptions, which often cannot be discovered and remedied, there is not much to be said about their electrical treatment.

As a palliative measure it may be used, but in so far as cures are concerned, they are not to be expected unless the cause of

* Abstract in *Archives d'Électricité Médicale*, August 10, 1912, p. 135.

the condition ceases to be operative. This may occur, and a patient with multiple arthritis may get quite well, although such a termination is rare as a spontaneous event. After vaccine treatment the disappearance of multiple arthritis is not so unusual, and electrical treatment is of value in promoting recovery in such cases. The following is a case of spontaneous recovery from advanced rheumatoid arthritis: A lady of middle age consulted me in the year 1900 for chronic rheumatic joints. She was unable to walk more than a few steps, and was carried into my consulting-room in a chair. She had a course of simple electric baths, about twelve in number, and considered that some improvement was produced. About nine years later the same patient came again. She then walked briskly, and had no joint trouble. Her reason for coming to see me was that there was some palpitation of the heart and circulatory trouble, for which she hoped to obtain relief by high-frequency applications, which she had been advised to take. She said that her rheumatic joints had gradually become better and better, and in the light of our present knowledge it is difficult to avoid the conclusion that she had in some way become rid of a focus of septic infection before the joint mischief had led to permanent damage of the articular ends of the bones. It may be that a loose tender tooth with pyorrhœa had caused her "rheumatism," and that the shedding of the tooth had saved the situation.

In ordinary cases of rheumatoid arthritis we are reminded of the dictum of Leduc, quoted in a previous paragraph, that successful treatment of joint affections requires that the original exciting cause shall have ceased to be operative.

Diathermy has been found useful in rheumatoid arthritis, though it possesses no specific curative effect, and the same may be said of high-frequency applications.

332. **Chronic Synovitis.**—The chronic synovitis of the knee-joints which is a not uncommon form of rheumatoid arthritis in elderly women can be favourably influenced by ionic medication. Salicylic ions are valuable, and so, too, are iodine ions, which may be used either with potassium iodide or lithium iodide solution. In the latter case the lithium entering at the anode may possibly contribute to the effect, but experience has not shown any great advantage from the use of lithium salts in joint cases, unless, perhaps, in those due to gout.

If iodide of potassium is used, there is an advantage in prescribing the liniment of iodide of potassium of the "British Pharmacopœia," to be used twice daily, and to be applied particularly by the patient a short time before the ionization. It serves to permeate the epidermal layers of the skin with the iodide, and so prepares the way for the ionization. In general, the patients can recognize definite improvement in cases of synovitis of the knees after five or six applications.

333. **Tuberculous Joints.**—In § 206 reference is made to the successful treatment of cases of this condition by continuous currents, and Bellemanière* has reported a similar result, which, however, may have been a case of fibrous ankylosis surviving after the tuberculous state had become extinct. The patient was aged fourteen, and had had trouble with one knee-joint since a fall at the age of four. When seen, there was fibrous ankylosis and lameness, and a pad was worn under the heel to assist walking. Scars suggesting old suppuration were present, and there were enlarged lymphatic glands in the neck and groin. After-treatment by salicylic ionization once a week with currents up to sixty milliampères given for twenty or thirty minutes, the patient improved, and in three months the joint had straightened, the ankylosis had disappeared, and he could walk well without the need for a pad beneath the heel. The muscles which were wasted from disuse also received treatment by means of foot-baths.

Danion has recorded a similar result in an elbow-joint ankylosed after tuberculous joint mischief. He used applications of continuous and of interrupted currents, and they were followed by marked improvement.

X rays have also been found useful in tuberculous joints (§ 206).

334. **Spondylitis Deformans.**—It is probable that this condition may be a variety of rheumatoid arthritis, and like that complaint, a sequel of some chronic infective process. One of my patients began to show decided signs of recovery after the removal of several bad teeth, and his improvement has been maintained. Salicylic ionization to the affected regions of the spine gives very distinct relief, and seems to be more effective in arresting the progress of the disease than any other mode of treatment.

* "Observation d'un Cas interessant de Tumeur blanche du Genou," *Annales d'Électrobiologie*, March, 1907, par A. et P. Bellemanière.

335. **Fibrositis.**—This term has been applied to various painful affections of the periarticular fibrous tissues, and of the fasciæ of the body. Maxwell Telling* has laid stress upon the presence of tender nodules or thickenings in the affected part, and states that in some cases an abundance of nodules of almost gristly hardness may be found if they are carefully looked for.

These cases are much relieved by ionization, and salicylic or iodine ions may be used.

Chlorine ionization has been successful in a certain number of cases of Dupuytren's contraction of the palmar fascia.

* "Nodular Fibromyositis and its identity with so-called Chronic Muscular Rheumatism," *Lancet*, January 21, 1911.

CHAPTER XVII

THE ORGANS OF THE SPECIAL SENSES

Anosmia—Xanthelasma—Episcleritis—Trachoma—Lachrymal obstruction—Corneal ulcer—Corneal opacities—Optic neuritis and atrophy—Nerve deafness—Tinnitus aurium—Xerostomia.

336. **Anosmia.**—The electrical treatment of loss of the sense of smell has been frequently tried. Ferrier* was successful in a traumatic case of long standing by using continuous currents applied between the base of the nose and the zygomatic fossa.

Other procedures, with intranasal electrodes, have been used by various writers, but probably an external position of the active electrode at the root of the nose is best. Loss of smell may follow loss of common sensation in the nasal passages, and may therefore be due to disease of the fifth nerve, in some cases, rather than to an affection of the olfactory nerve.

337. **Atrophic Rhinitis.**—The treatment of ozæna has already been referred to in § 296. Many authors have reported favourably upon the effects of treatment by ionization with copper. More recently Carreras† has recommended the use of high-frequency, with a vacuum electrode. He says the results could not be better. The treatment is without pain, and should be used every other day for five minutes. The effect is probably due to direct stimulation in part, and in part to the antiseptic action of the effluve of the high-frequency electrode (§ 189).

338. **Antral Suppuration.**—Attempts have been made to control this condition by ionization. In conjunction with Mr. Harmer, I have applied zinc ionization, using a special irrigation electrode. As a result a great change in the bacterial conditions was noted, but it proved temporary. Probably a better result would have followed if the ionization had been

* "Localization in Brain Disease," 1878.

† *Archives d'Électricité Médicale*, 1911, vol. i., p. 256.

repeated at short intervals. In another case a better result was obtained, and the patient seemed to have been cured.

339. **Xanthelasma Palpebrarum.**—Electrolysis is useful in this condition. The negative pole should be used, and the electrode should be a steel needle. The patch is to be treated by holding the needle vertically and electrolyzing it all over with a succession of punctures.

Villard and Bosc,* in writing on this subject, have given the following account of their method: The treatment is carried out at one sitting. For small plaques of 4 or 5 mm. a single puncture only is required; for larger ones, the patch is divided into areas which are successively punctured. The important point is to neglect no part, and even to go slightly beyond the limits of the diseased area. The needle is inserted into the skin of the plaque parallel to the surface for a distance not exceeding 10 mm., and the current is slowly increased to six or eight milliampères. After two to four minutes it is gradually reduced again to zero.

During the electrolysis the skin of the plaque becomes greenish in colour, while the needles are surrounded by a frothy zone. The electrolyzed skin forms a superficial slough, which comes away eight to fifteen days later. A scab then forms, which falls off two or three times before cicatrization is completed about three or four weeks later. As the result the xanthelasma disappears, and a smooth cicatrix remains.

The galvano-cautery may also be used, with a fine point, and brief punctures. It is rather less painful than the electrolysis, because it lasts less long.

340. **Ophthalmia Neonatorum.**—Ramsden† has reported the treatment of a case of this condition by zinc ions. The eyelid was everted, and a pad of cotton-wool wet with a 2 per cent. solution of zinc was applied. A current of 0·5 milliampère was used for three minutes, and was repeated twelve hours later. In two days the case was cured. The author considered the result to have been much better than he could have expected from his experience of such cases with silver nitrate or protargol as ordinarily applied.

341. **Trachoma.**—Mayou‡ has treated this condition by X-ray applications. In his cases the affected eyelid was everted, and

* *La Clinique Ophthalmique*, 1903.

† *British Medical Journal*, November 7, 1908.

‡ "The Uses of X rays in Ophthalmic Surgery," *Archives of the Roentgen Ray*, vol. vii., p. 61, January, 1903.

a two-minutes' exposure given on four or six successive days, and this was repeated after a few days' rest. Twelve or fifteen applications were needed to effect a cure. Where one eye only was treated, while the other was shielded from the rays, the cure was confined to the treated eye. Radium has also been used in trachoma, and good results have been claimed for it.

W. J. Morton* reported in 1895 a series of cases of trachoma treated by copper ions; several were cured. The eyelids were everted, and a copper rod moved slowly over the surface, using a current of two or three milliampères in some cases, and as much as ten in others, in accordance with the tolerance of the individual case. This was done for two or three minutes. From four to twelve treatments were necessary.

342. **Episcleritis.**—This rheumatic or gouty affection of the conjunctiva may be treated by means of salicylic ions applied over the closed eyelid with a current of from five to ten milliampères, according to the toleration of the patient, given for five or ten minutes (Leduc). Salicylic ionization to the forehead and cheek has proved useful in a case under my care. The modified method was adopted by reason of the tenderness of the eyeball; but after a single application the whole of the episcleritis cleared up, so that no second application was required.

343. **Lachrymal Obstruction.**—Jessop and Steavenson† have given an account of ten cases of lachrymal obstruction treated by electrolysis. The instrument used by them was a curved platinum probe. The current required is small, two to four milliampères being sufficient, and the duration is thirty seconds. No anæsthetic is needed; the probe must always be negative, the positive pole being the usual plate electrode. Two or three sittings suffice to produce cure of the obstruction. The cases related are confined to those in which the obstruction was at the punctum or in the canaliculus, and not in the sac itself. The operation is simpler than the slitting up of the canaliculus, and the improvement is permanent.

344. **Corneal Ulcer.**—At the Annual Meeting of the British Medical Association in 1910‡ I read a paper on the treatment of some corneal ulcers by zinc ions, and at the same meeting a

* "Electric Medicamental Diffusion," *Journal of the American Medical Association*, May 4, 1895.

† *British Medical Journal*, 1887, vol. ii., p. 371.

‡ *Ibid.*, August 27, 1910.

paper was also read in the ophthalmic section, by H. M. Traquair,* on the treatment of purulent keratitis by zinc iontophoresis.

The first of these papers dealt with the treatment of the intractable condition known as "Mooren's ulcer," and recorded four cases. The first was done in 1907. Two of these were healed permanently by one application, and the others after two or three. The electrode consists of a fine tuft of wool moistened with zinc sulphate (1 per cent.), and attached to the end of a zinc rod. This can be brought into contact with the cocainized cornea. A current of a milliampère for five minutes usually suffices, but rather more current or a longer time should be allowed for the larger ulcers. A lotion of zinc sulphate instilled afterwards at intervals tends to prevent reinfection of the cornea, and reduces the conjunctivitis.

Traquair has contrived an ingenious form of electrode which consists of a cap of celluloid with a hole at its end. This is partly filled with cotton-wool, which also projects slightly through the hole, and the cap fits over the end of a zinc rod. This electrode can be used with gentle friction over the surface and edges of the ulcer during the application, and this favours the penetration of the zinc to every part of it. Traquair also insists upon the value of a preliminary wiping of the ulcer, and effects this with a tuft of wool on a probe. This is also wetted with the zinc solution, whose strength is of 0·5 per cent. His results were good, both as to quickness of healing and as to character of the resulting scar. Of twenty cases investigated bacteriologically, fifteen were pneumococcal in origin.

345. **Corneal Opacities.**—Valuable results may be obtained by the treatment of corneal opacities by the continuous current. Alleman† states that he is convinced, from the observation of a number of cases extending over a considerable time, that the use of electricity promises the only treatment of value in this condition. He applies the kathode to the cocainized cornea, using as electrode the end of an amalgamated silver rod seven millimetres in diameter, with one-half to four milliampères for one or two minutes. The amalgamated surface being semifluid, effects a softer and better contact.

I have had several cases in which considerable improvement in vision has followed the treatment. The application may be

* See *The Ophthalmic Review*, January, 1911.

† *Brooklyn Medical Journal*, November, 1890.

made through the closed eyelid, as the lachrymal secretion provides a layer of sodium chloride solution in contact with the nebula. Cocaine is then not needed, and larger currents (five milliampères) can be borne. The effect is doubtless one of the sclerolytic action of chlorine ions. The negative pole must therefore be used as Alleman has directed.

Pansier, in an excellent book,* has also reported a number of cases. He expresses the opinion that there is no advantage in applying the electrode directly upon the corneal surface.

Synechiæ have also been softened and removed by ionic applications. Pansier has published a case.

346. **Optic Neuritis and Atrophy.**—Electrical applications of continuous current have been used for optic atrophy and optic neuritis, and several cases have been reported in which improvement of sight has followed. When atrophy comes on without previous optic neuritis, the prospects are considered less favourable. The treatment is by transverse currents through the temples, with reversals, and by longitudinal currents through the head, with the anode over the closed eyelids.

The prospects of improvement depend much upon the nature of the disease. In tabetic atrophy, good results could hardly be expected, but Capriati† recommends a trial of the method, and considers that he has obtained improvement by using currents of two milliampères applied longitudinally. His views have been summarized as follows: Electrical treatment is indicated in tabetic atrophy of the optic nerve in cases in which the disease is not running a very rapid course, and before it has reached a very advanced stage. If employed in the early stages it appears to do good, and, with certain limitations, tends to arrest the morbid process, apparently by acting on the nerve fibres still unaffected. Better results may be anticipated from the application of the current antero-posteriorly than transversely, although neither method has yielded results warranting great enthusiasm. In neuritis affecting the nerves of special sense we usually have to deal with a progressive and degenerative state, and on this account treatment does not give results like those which may be expected to follow simple traumatic lesions of the ordinary mixed nerves.

* *L'Électrotherapie Oculaire*, A. Maloine, Paris, 1896.

† *Riforma Medica*, October, 1893. (Abstract in Weekly Epitome of *British Medical Journal*).

Ludwig Mann* has also seen occasional benefit follow electrical applications in ten cases of atrophy and retrobulbar neuritis.

In retinitis pigmentosa and in certain other retinal conditions (syphilitic neuro-retinitis, retino-choroiditis) it appears that a favourable effect may be produced by applications of continuous current. M. Gunn† has recorded 18 cases of optic nerve atrophy, of which 6 were improved, 4 were doubtful, and 8 were not benefited. He concludes that the prognosis is best in young or middle-aged people with recent failure of sight, and ability to count fingers at least. In retinitis pigmentosa the results were much more encouraging. Of two cases under his own care, and of two others, he reports that "all were improved."

Pansier considers the continuous current useful in chronic iritis.

347. **Auditory Nerve Deafness.**—The treatment of nerve deafness by electricity sometimes gives good results.

Fig. 171.—Aural Electrode.

The auditory nerve can best be tested or stimulated by a bifurcated electrode, which can be applied to both ears at once (Fig. 171). By proceeding in this way there is less likelihood of making the patient giddy (§ 174). The continuous current should be used, with the negative pole to the ears. The current should be caused to vary gradually during the whole time of the application, either by using a rhythmic interrupter, or by turning the current on and off by hand with the current collector. The strength should not exceed ten milliampères. The patient must be watched for signs of faintness, as this may be produced if the currents are too strong. The application may be for ten minutes.

* *Zeitschrift für Physik. und Diät. Therapie*, November, 1904.

† Royal London Ophthalmic Hospital Reports, vol. x., 1881.

An inch is a suitable diameter for the electrode surfaces. If they are less than this some soreness of the skin may be produced at the points of contact from electrolytic action. A small pad of moist absorbent wool placed between the electrode surfaces and the skin improves the contact. These precautions are necessary because the electrodes are so small, and the density of current is consequently great.

By persevering with this treatment many patients will experience decided improvement, and a good effect may even follow the first applications, and the result may be lasting. Intelligent patients can be taught how to carry out treatment for themselves, and should be encouraged to persevere for one or two months.

348. **Tinnitus Aurium.**—Subjective noises in the ears can often be relieved by a course of treatment with continuous currents in the manner described in the preceding section.

Tinnitus complicates nearly all the different forms of ear disease; for instance, it may depend upon the accumulation of wax, or it may be due to some other temporary disorder of the ear, or, in patients whose auditory apparatus is otherwise normal, it may occur from the action of drugs, from changes in the circulation, or as a part of some general morbid condition.

More commonly, however, some chronic ear mischief exists and the removal of the subjective noises may be a matter of great interest to the patient, even apart from his deafness. When patients are electrically tested, it is found that sometimes the tinnitus is associated with greatly increased irritability in the auditory nerve, which is shown by the ready production of an impression of sounds by small currents. As a rule, the kathodal closure produces an increase of sound and anodal closure reduces the sensation of sound which is felt, and this effect is very well marked in these patients. The effect of the anode in temporarily diminishing the noises is sometimes very apparent. The usual effect of the application of the anode to the ears is to diminish the noises, while that of the kathode is to increase them. This electrical hyperæsthesia is not necessarily a favourable sign.

Various other electrical applications have been advised for tinnitus aurium. Brigade-Surgeon W. Price, writing in the *British Medical Journal* in 1900, describes a method with the induction-coil current which he has found efficacious in his own

case. He applies the current to the external ear by one electrode and completes the circuit through his feet.

The brush discharge of the static machine or the effluve of high-frequency directed into the external auditory meatus has also been recommended.

When a high-tension pulse exists, general applications of high-frequency may be used.

349. **Eustachian Obstruction.**—Cumberbatch and Steavenson* have described a method of electrolyzing the Eustachian tube in cases of deafness associated with pharyngeal catarrh. Their instrument consists of a vulcanite Eustachian catheter and an electrical bougie (Fig. 172). The bougie is made of a fine flexible

FIG. 172.—EUSTACHIAN CATHETER ELECTRODE.

copper cord about seven or eight inches long, insulated by vulcanite to within an eighth of an inch of its end. The catheter is first placed in position, and the bougie is then passed along it. A pad connected with the positive pole, and placed at the back of the patient's neck, completes the circuit. A galvanometer should be included in the circuit, and the current gradually increased up to four milliampères. A crackling noise will be heard by the patient. The electrolysis is kept up for three or four minutes, and usually before the expiration of that time it will be found that the bougie can be pushed on for a small distance. Improvement in hearing is certainly produced in some cases by this procedure, but it is difficult to carry out.

350. **Otosclerosis.**—Treatment by electricity in this affection has not yet yielded any results of value, but when thickening of the tympanic membrane is a result of local mischief, ionization may improve the hearing. This was the case in a patient with deafness in one ear after a perforation of the drum which had followed measles long before. Chlorine ionization with the meatus filled with salt solution produced a marked and permanent good effect after six or eight applications.

* *Lancet*, November 24, 1888.

Bourgeois has similarly stated that he had obtained improvement in hearing, and decrease of tinnitus when the cases treated were cicatricial conditions left after old inflammations or suppurations.

W. J. Morton* in 1894 reported a case in which he treated a patient with success for deafness and tinnitus by ionization of the region round the Eustachian tubes, in the pharynx with copper ionization; and J. Taylor† in 1909 mentioned the case of a child under treatment for ozœna by ionization of the nasopharynx, who was also improved as to the deafness which was present. It is possible that this line of treatment deserves further investigation.

351. **Otorrhœa.**—A medical friend has informed me that he has had good results from the treatment of otorrhœa by ionization with zinc. The meatus, after being cleansed, is filled with a warm solution of zinc sulphate and a positive wire is introduced. Its sides are shielded by a loose rubber sleeve to protect the sides of the meatus from direct contact with the metal, and a current of three or four milliampères is gradually applied, and as gradually turned off after the lapse of six minutes.

352. **Xerostomia.**—In the rare condition of "dry mouth," electrical applications may be of service. In a patient of my own this condition was very marked. There was hardly any flow of saliva under ordinary circumstances, and the patient found it difficult to chew any dry form of food. By the daily use of continuous current to the regions of the salivary glands, a gradual improvement was set up, and eventually the patient was able to discontinue the treatment, as it had become unnecessary. The treatment was carried out at home by the patient, and consisted of two parts. One was the application of a bare zinc electrode to the cheeks and tongue, particularly to the regions around the orifices of Stenson's and Wharton's ducts, with a continuous current of two or three milliampères, and the other part of the treatment was the stimulation of the parotid and sublingual glands of both sides by interrupted currents applied externally.

* *Journal of the American Medical Association*, May 4, 1895.
† Bristol Medico-Chirurgical Society. (Abstract in *British Medical Journal*, May 12, 1909.)

CHAPTER XVIII

CUTANEOUS AFFECTIONS.

Nævus—The removal of hair—Ringworm—Sycosis—Boils and Carbuncle — Alopecia — Warts — Psoriasis — Pruritus — Hyperidrosis — Chronic ulcers—Lupus—Keloid—Mycosis fungoides—Guinea Worm.

353. **Electricity in Skin Diseases.**—There is no branch of medical treatment which has derived more advantage from electrical applications than the department of diseases of the skin; and yet, until about fifteen years ago, electricity was almost completely neglected in dermatology. The X rays have a very marked action on the skin, and in moderate doses they seem to stimulate its activity in a favourable way. Almost all skin diseases have been treated by X rays, and usually with success. It is probable that the healing of a cancerous ulcer under X-ray treatment is nothing more than a stimulation of the natural tendency to repair, and to the active formation of epithelium. In § 207 a striking instance of the healing over of a large ulcer of the breast in a case of recurrent cancer has been described.

The effluve of high-frequency is also a very valuable stimulant to the skin, and this too has been found useful in numerous forms of skin disease, and it is interesting to note, in the older works on electrotherapeutics, that the brush discharge of the static machine had been observed to lead to good results in various skin affections, and even in promoting the healing of ulcers. Those who wish to pursue the subject of X rays in skin diseases should consult the " X-ray Treatment of Skin Diseases " by F. Schultz, translated by J. Burnett.*

Ionic medication has also found useful applications in dermatology. The accessibility of the skin makes it peculiarly suitable for treatment by the introduction of drugs with the electric current, and, as will be seen in the succeeding pages, successful results can be secured in this way.

* Rebman, London, 1912.

354. **Nævus.**—Electrolysis is a convenient mode of treatment for nævus, and for certain cases it is superior to all other methods; but to secure good results a certain amount of practice is necessary, and several repetitions of the operation may be required if the nævus is an extensive one. The chief art in treating a nævus by electrolysis lies in the careful regulation of the current used and in knowing when to stop. It is easy to electrolyze a nævus in such a way as to destroy it and cause it to slough away completely, but this leaves a large scar, and is not the best way of attaining one's object. The object to be aimed at in the electrolysis of nævi is to carry the destructive action just so far as to coagulate the blood and break up the bloodvessels without producing a general necrosis and sloughing of the whole. When the nævus is entirely subcutaneous, it is most important to save the skin, for then the nævus is removed without any scar, except at the minute points where the needles were introduced. When the nævoid tissue is quite superficial and very florid, and involves the actual thickness of the skin, it is impossible to destroy it without some scarring. In a large number of cases the galvano-cautery, if dexterously used, gives results which are as good as those of electrolysis, and gives them more rapidly; but a fine point is required, and it must not remain long in one place, and it must be made to penetrate the full thickness of the nævus. A superficial searing is of no use. The introduction of carbon dioxide snow has largely supplanted the other methods of treatment for nævus, but it is not useful in all kinds of cases.

Those nævi which can be easily excised should be treated by that method, and electrolysis or cautery should be reserved for those which are difficult to do in that way or by "freezing." If the nævus is very small—that is to say, under a fifth of an inch in diameter—it may be completely destroyed in one sitting, and the resulting scar will not be of any great moment; and here I would urge very seriously the importance of dealing with nævus at the first possible opportunity after birth. Nævi which are quite small at birth are often allowed to grow large before any interference is thought necessary, with the result of disfigurement which might have been prevented. Unless nævi are large, the first application should aim at complete destruction, or at least the major part of the nævus should be got rid of at the first treatment.

Nævi may spontaneously disappear, but this is a rare occurrence, and the usual tendency of a nævus in the young baby is to grow rapidly. Indeed, after treatment a nævus will often commence to grow afresh, although at the time of operating it seemed to have been completely destroyed. Such reappearance may take place in a nævus which has been perfectly healed for two months. The margin of a nævus is the part most prone to fresh growth, and this part must be attacked most thoroughly.

Nævus is commoner in females than in males, and it is found on the head and neck more often than upon the trunk or limbs. Out of 1,341 cases in the Electrical Department of St. Bartholomew's, 900 were in female and 441 in male children; in about half of them the nævus was situated on some part of the head or face. Nævus may occur on the ocular conjunctiva. At the anterior fontanelle nævi are common, and can safely be treated by electrolysis; the needles, of course, must not be pushed into the brain.*

The usual plan of treatment is as follows: Needles attached to one or both poles of a battery are introduced into the nævus, a galvanometer being included in the circuit; the current is then very gradually raised from zero up to 20, 30, or 40 milliampères.

If both poles are used, care must be taken that needles of opposite poles do not touch one another, for if they remain in contact the current simply runs to waste through the metallic circuit so produced, and the nævus tissue is unaffected; if they come into momentary contacts, the patient receives a shock each time they touch and separate. Soon after the commencement ot the operation the tissues round the needles begin to change colour; round the positive needles there is hardening and pallor, and round the negative needles frothing is produced with the evolution of hydrogen gas. The positive needles become firmly adherent to the tissues in which they are embedded, and force is required to withdraw them; on this account bleeding is more likely to occur with the positive than with the negative needles. The negative needles become loose and are apt to slip out, but they must not be allowed to do so, for the current must not be suddenly interrupted. If the tissues round the needles become livid or blackened, sloughing of the

* For further statistics see a paper by Lewis Jones in the Proceedings of the Royal Society of Medicine, vol. ii. (Electrotherapeutic Section), p. 107.

part will follow. This change shows itself first at the negative pole. The position of the needles must be altered before this by taking them out and reinserting them one at a time in other parts of the nævus until the whole of it has been treated.

The needles are to be withdrawn after the current has been lowered, and must not be plucked out while the current is still running strongly. The positive needles may be adherent, and should be twisted out gently. A little bleeding may follow from one or two of the punctures, but it is rarely of any importance. The after-treatment is simple. Collodion containing iodoform (one drachm to the ounce) is to be painted over the nævus. This can be left for four or five days, but should then be removed, and the place treated with boracic ointment, or if any suppuration or local sloughing should develop, some zinc lotion on lint will be a suitable dressing. Many nævi heal quickly, and need no second application. It is impossible to avoid some destruction of the skin and some scarring when the nævus is cutaneous, but the scars produced are much smaller than might be expected, and when seen a year or two afterwards they show remarkably little.

Sometimes only one needle or set of needles, usually the negative, is introduced into the nævus, the circuit being completed through the patient's body by using a large pad for an indifferent electrode. In this case the resistance is higher, and a larger number of cells is required, and there is a greater risk of shock or faintness, especially with nævi on the head or face. This unipolar method is most suitable in cases where great nicety is needed, as, for example, in small nævi about the eyelids or nose.

The rate of destruction depends upon the density of current in the part. If needles of both poles are introduced irregularly, it is very likely that the current may be strong round the points where they are nearest together, and be weak in the more remote parts. The diagrams (Fig. 173) represent the conditions under two different arrangements of needles, first with the needles placed evenly, and the density of current uniform; and, secondly, with the needles close together at the points, and the current concentrated unequally.

In order to simplify the introduction of the needles in a proper manner, the writer* has devised an instrument (Fig. 174) con-

* Lewis Jones, "An Improved Instrument for the Electrolysis of Nævi," *British Medical Journal*, February 20, 1892.

sisting of a handle to carry the needles. Two, three, four, or five can be screwed into it, and they are so arranged as to be alternately positive and negative (see the smaller of the two figures). By this means the needles are kept at equal distances

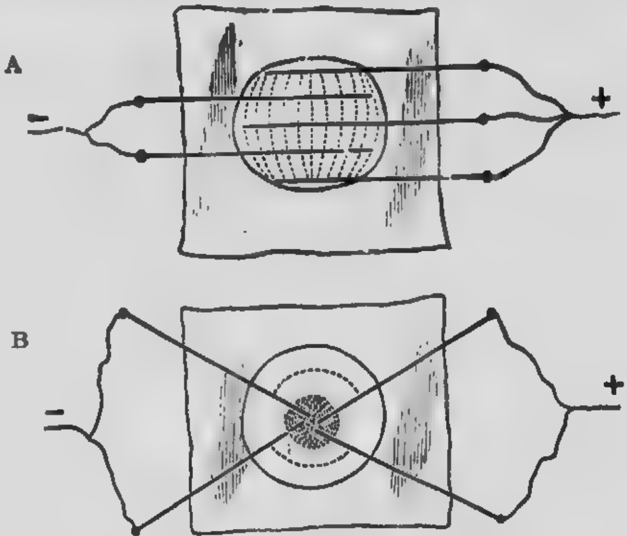


FIG. 173.—ELECTROLYSIS OF NÆVUS.
(*A*) Proper and (*B*) improper position of needles.

from one another throughout the operation, and they cannot touch accidentally, and they can be moved about simultaneously inside the nævus, so as to bring the whole of it under the action of the current. It is made by Arnold and Sons.

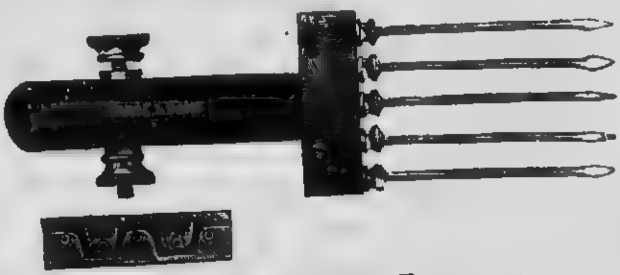


FIG. 174.—BIPOLAR FORK ELECTRODE.

A modified form of this instrument, which presents certain advantages, has been devised by W. T. Freeman, and is made by Messrs. Down Brothers. It has the advantage of permitting the use of sewing-needles, but the caution given on p. 312 respecting the use of steel needles must not be lost sight of.

The needles should usually be introduced in a direction parallel to the surface, though in some superficial nævi a multiple puncturing with a vertical needle gives the best results. Sufficient skin survives between the punctures to preserve the mark from being truly cicatricial.

It is difficult to formulate a rule for the current to be used, but it is the density of current which is the important point, more so than the actual number of milliampères employed. The current density should not exceed twenty milliampères per inch of positive needle. Thus, with four needles introduced for a distance of half an inch, two being positive, a current of twenty milliampères would be amply sufficient, and with two needles introduced for twice that distance the same current would yield the same effects.

X rays have also been used with success in the treatment of nævus, and in one or two instances in which nævi were growing with extreme rapidity, so that electrolysis and galvano-cautery seemed to stimulate rather than to check their growth, I have known full doses of X rays arrest the growth completely, and lead to their complete shrinkage and disappearance. This was also happily the case in a rapidly growing, pulsating nævoid growth of the nose in a girl, in which ligature of all the blood-vessels supplying the nose on that side had completely failed to arrest its progress. Several maximal doses of X rays were given at intervals of three weeks before the desired effect was produced.

Radium is also useful for nævi, and, like the X rays, it appears most valuable in cases which are in active growth.

355. **Stellate Veins.**—The small nævoid spots which appear on the face in growing children and less commonly in adults, are best treated by puncture with a zinc needle connected to the positive pole. A very small current for a short time (0·5 milliampère for half a minute) usually suffices to obliterate them without leaving any mark.

These stellate veins are of interest. If examined closely under a glass compressor, a pulsating vessel can usually be seen at their central point, so that they are probably minute arterio-venous aneurysms, and this would explain their tendency to grow larger. When they have existed for a long time, the stellate condition changes to one of a meshwork; when this stage is reached a single central puncture may not obliterate the whole,

as some of the collateral centres may survive ; these, therefore, should also be punctured if conspicuous.

In some cases the stellate veins come from a scratch of some kind ; in others they are probably due to the bites of gnats or mosquitoes.

The dilated veins of the nose, which follow repeated attacks of acne, are also best dealt with by needling. Great improvement can be brought about in the appearance of the nose by careful treatment of this kind. A zinc needle acts best.

356. **Port-wine Mark.**—This form of nævus can be attacked by a tattooing process, using a fine needle, and inserting it vertically into the skin ; the current used must be one milliampère, and the application at each point quite brief. The operation should produce minute points of destruction without confluence of the resulting minute scars. The negative pole is best. In some port-wine marks the position of many of the capillaries can be seen, and these are the points into which the needle must be especially directed. When the individual vessels cannot be distinguished, the cases are less favourable. The result is a distinct improvement in the aspect of the surface. The treatment must be carried out slowly. It is so long a process that it is not often undertaken.

Radium is also used for this condition.

357. **The Removal of Superfluous Hair.**—If a fine needle connected to the negative pole of a battery of three or four cells be introduced into a hair follicle, electrolysis takes place round the needle when the circuit is closed, and the hair follicle is destroyed by the alkali produced ; the hair can then be removed easily, and does not grow again.

The method of operating is as follows : The patient should recline in a good light. Having placed the indifferent electrode (anode) in contact with a convenient part of the patient's body, the kathode is attached to a fine platinum wire set in a handle, and the current collector is turned on to take up three cells into circuit. The operator then introduces the needle as closely as possible to the root of the hair, holding it in the proper direction for it to enter the follicle. The needle passes down readily to the required distance (one-eight or one-sixth of an inch), a current of about two milliampères passes, slight effervescence is seen at the orifice of the follicle, and at the end of five seconds or so the needle is withdrawn. As a rule, the hair can then

be lifted out easily by a forceps ; if it still remains firm, the needle may be introduced a second time until it is loosened, though this is best avoided. There is a certain amount of pain, but it is within the limit that can be borne without flinching, and an anæsthetic is not necessary. Cocaine cannot be usefully applied.

It is best to use for the needle a very fine platinum wire, blunt-pointed, because such a needle is less likely to penetrate easily and so to pass away from the hair follicle. It should be sterilized before use by heating to redness, and is better than a steel needle. The latter will leave indelible black marks if by accident it be used when connected to the positive pole. The current must be closed before the needle is inserted into the follicle. A key in the handle is therefore unnecessary and troublesome.

A good deal of practice is required to perform this little operation skilfully, for it really amounts to a catheterization of the hair follicles. No force must be used in removing a hair ;

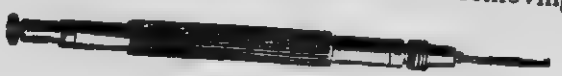


FIG. 175.—NEEDLE-HOLDER ELECTRODE.

if force is used the hair will come out before the follicle is destroyed, leaving its root behind and a new hair will grow up from it. It is possible with a good patient to remove thirty or forty hairs at a sitting. A tiny eschar with a small zone of redness is left round the follicle. Several hairs in close proximity should not be attacked at one time, for fear lest the injury to the skin should lead to a scar, but the hairs should be removed sporadically.

It is as well to caution patients that there will be a certain percentage of returning hairs, but that these can be dealt with a second time if any should so return.

It is very easy to overdo the treatment and leave scars. It is not wise to attempt the total removal of a fine downy growth of the upper lip of young women.

The permanent removal of superfluous hairs from the skin by exposure to the X rays requires very careful management to cause the desired shedding of the hairs without producing injury of the skin itself. The risks of causing some damage to the skin have deterred many operators from using this method

of removing hairs for cosmetic purposes, although in cases such as sycosis and tinea, where the hair must be temporarily removed for the cure of disease, or in unsightly hairy moles, the removal of the hair by X rays is frequently performed.

Its risks as a cosmetic process are due to the probability of injurious effects upon the texture or colour of the skin, such as pigmentation, reddening, or the formation of telangiectases, the appearance of which would suffice to defeat the desired object of improvement in the personal appearance.

It is comparatively easy to cause hairs to fall out as a result of X-ray applications, but it is difficult to do it in such a way as to prevent their return subsequently. The procedure is to cause a temporary falling out of hair, as in Sabouraud's treatment of ringworm (§ 360), and to repeat this after the lapse of one or two months. Several such repetitions produce a more or less complete and permanent disappearance of the hair. Noiré* advised the use of rays filtered through aluminium, and this method is now adopted.

Many people have attempted to develop the use of X rays for hypertrichosis, either by the use of filtered rays or by the method of repeated small doses. Rayner† has described his method in a recent paper, and considers his results to be an improvement on those previously obtained. His method is as follows: The tube is a small one six or seven inches in diameter, and it is used with the antikathode at 15 centimetres from the skin. The pastille and the aluminium filter are 7·5 centimetres from the skin, and the former is not covered by the aluminium filter. The hardness of the tube is 6 or 7 Benoist. A Sabouraud dose is given. The filter is half a millimetre thick. An interval of from one to three months should elapse before a second application.

Savill‡ has reported a case in which epilation was carried out in 1910 without any erythema or dermatitis, but in 1912 some development of telangiectases commenced. The treatment given had seemed completely successful up to that time. The technique employed was that of Bordier,§ with an aluminium filter of 0·5 millimetre, and a pastille on the skin giving Bordier's

* *British Medical Journal*, October 24, 1908.

† *Ibid.*, August 31, 1912.

‡ *Lancet*, August 24, 1912.

§ See *Archives d'Électricité Médicale*, December 25, 1909.

tint O (feeble) repeated on three successive days. The writer therefore published the case as a warning that these telangiectases may appear even after the greatest care has been exercised, and at a period as late as two years after the irradiations.

358. **Ingrowing Eyelashes.**—The removal of eyelashes for trichiasis is satisfactorily accomplished by electrolysis, but it is difficult to carry out, owing to the sensitiveness of the part, and the fineness of many of the most troublesome hairs. The results of the treatment of this complaint are very satisfactory. Usually at the commencement of the treatment the corneæ are hazy, in consequence of the continued irritation by the turned-in hairs, but if the removal of the hairs be persevered with until every one has been removed, the corneæ will recover their transparency.

359. **Moles.**—The best treatment for small hairy moles is epilation. When the hairs have been removed, very little will be seen of the mole, for the prominence on which the hairs grow will disappear. A good deal of the pigmentation of the skin between the hairs will also disappear when they have been taken out; but if there be much pigmentation left, the mole should be electrolyzed with a zinc needle in several directions, with a current of two milliampères for a minute. Carbon dioxide snow can also be used for the flattening down of a raised mole.

360. **Tinea Tonsurans.**—The treatment of ringworm of the scalp by X rays has been made a practical success by the labours of Sabouraud. Good descriptions of his mode of procedure have been given in English medical journals, including the address given by Sabouraud himself before the Dermatological Society, and printed in the Journal of the society.* In the treatment of ringworm the point of chief importance is the dosage of the X-ray applications, and this is effected by means of the pastilles of platino-cyanide of barium, described in § 145.

For a single patch it may suffice to depilate the affected area only, but it is common to find other affected areas, and then it is best to treat the whole hairy scalp. Formerly this was done in a number of successive exposures, and each piece was covered by a sheet of lead after it had received its dose of rays, to protect

* "The Radiotherapeutics of Ringworm at the Municipal Laboratory of the City of Paris at the Hospital of St. Louis," R. Sabouraud. *British Journal of Dermatology*, June, 1906, with Plates.

it while the neighbouring areas were under treatment; but an improvement has been made in this respect, and the troublesome shielding with plates of lead can now be dispensed with. This is done by the method attributed to Kienböck, and developed in this country by Adamson. It is known as the "five exposure" method, and consists in exposing the scalp to five doses of X rays, aimed in such directions that although there is overlapping of areas, the overlapping is so arranged that the whole scalp gets a uniform amount of rays.

The whole is completed at one sitting, and occupies from one and a half to two hours. The following are the details given by Adamson:*

1. The hair is clipped short over the whole head to facilitate operations.

2. Five points are marked on the scalp with a blue skin-pencil as follows: One at a point 1 or 2 inches behind the frontal margin of the hair; a second 1 to 1½ inches above the centre of the flat area which forms the upper part of the occiput; the third is just above the lower edge of the scalp, at the lower part of the occiput; and the fourth and fifth are on the sides of the scalp just above and in front of the right and left ear. The first three are in the median line. Measured with a tape measure, the distance between any two of these points should be exactly 5 inches. They are joined together by lines drawn with the skin-pencil, which should meet at right angles. A Sabouraud dose is given to each of these areas in succession, with the antikathode at a distance of 6 inches, and placed exactly over each of the marked points in turn. The centre of each area thus receives the rays vertically, and its margins receive them with increasing obliquity. These margins receive a partial dose, but it becomes a full dose when all the applications are complete, as the parts rayed obliquely receive a dose during more than one of the five exposures. The forehead and other non-hairy parts are screened.

At the conclusion of the exposures the scalp exhibits no change in appearance, and will remain thus for about fifteen days, but after that time the hair will fall under the influence of the smallest traction, all the hairs having their root-ends atrophic and pointed.

After the exposure the head should be washed daily with soap

* "A System of Treatment," by Latham and English, vol. iii., p. 356. Churchill, London, 1912.

and water, and a lotion of tincture of iodine, 1 part, and methylated spirit, 7 parts, applied, in order to avoid the dissemination of spores, for the fungus is not killed by the X rays.

When the head has been bare for ten to fifteen days, the roots of trichophytic hairs may still be seen embedded in the skin. They are the last to fall, and must not be allowed to remain, for they might reinfect the new hair. The daily washings will remove them, and by the thirty-fifth day the head thus treated should be entirely bald and free from all diseased hairs.

Sabouraud states that the head thus treated remains bald for two months. It then becomes covered with lanugo and adult hairs, sometimes at first in a very irregular way. At other times, again, the healthy hair comes back in islands, marking exactly the place of the ringworm patches. In any case, the new growth ought to be, in normal circumstances, complete within four months.

When Sabouraud's dose has been exceeded, the regrowth is likely to be retarded in places for a month or six weeks, and it must be understood that hair which has not come back within six months will never grow again. After exposures which have been too strong, but yet not excessively so, a permanent loss of hair may result, although no dermatitis may have been produced. The X-ray treatment of ringworm is, therefore, a delicate method.

Sabouraud further adds that there are many degrees between perfect growth, on the one hand, and the complete destruction of the hair bulbs on the other. When the tint B has been exceeded, one may see a growth which is woolly, crinkled, and "Ethiopian." Or, again, upon a patch which has been too much treated the hair may come back thinly.

Insufficient applications also conduce to different bad results. Diseased hairs may remain, and the whole process may require doing afresh. Such a second exposure should not be made on the same place within the month, but after the lapse of this time the exposure may be made anew without running any more risk of lack of regrowth than at the first sitting.

The proper position of the pastille is at 7·5 centimetres from the target, while the region irradiated should be at exactly double that distance—viz., 15 centimetres. The pastille should be distant at least 2·5 centimetres from the glass wall of the tube, in order to avoid a misleading effect from the warmth of the glass,

which tends to vitiate the indications by accelerating the colour change in the pastille. A small X-ray tube is therefore essential.

Sabouraud considers that idiosyncrasy may be neglected in X-ray work, and states that two of his nurses have made 7,000 exposures since May, 1904, without coming across one instance of idiosyncrasy, and without a single case of dermatitis, by relying upon the indications of the pastilles of platino-cyanide of barium.

Adamson has designed a special box-shaped tube-holder for epilation work. It is fitted with three pegs which rest upon the scalp and insure that the tube is at the right distance.

Ionic medication with salts of copper or zinc has been used for ringworm. The writer has obtained interesting results with both of these metals in cases of ringworm, the bald patch becoming rapidly covered with a growth of healthy hair after one or two ionic applications. Care must be taken to remove grease from the affected area before commencing the electrolysis, as, if this is not done, there is considerable difficulty in obtaining a uniform penetration of the drug. A preliminary soaking for half an hour of the area to be ionized with the solution upon several thicknesses of lint is useful. A serious difficulty in the use of the ions for the cure of ringworm is that a few follicles are likely to escape the action through being blocked with greasy material, and these may preserve the fungus and lead to a relapse. Riddell* has had successes by using solutions of mercuric chloride or iodide. He applies it for forty-five minutes two or three times a week, and describes this mode of ionic application as safe, rapid, and certain.

361. **Favus.**—The X-ray treatment recommended for ringworm may also be used in favus. Sabouraud states that favus with scutula is not cured with certainty by a single exposure to X rays, though one application, if well made, may cure four-fifths of the disease. His advice is to practise depilation by forceps over any points upon the exposed surface at which new scutula have made their appearance. Less severe cases of favus without scutula may ordinarily be cured in one sitting.

362. **Sycosis.**—This condition may be treated by the method of causing depilation by X rays, as in ringworm of the scalp.

* *Glasgow Medical Journal*, February, 1912.

E. S. Worrall* has reported three successful cases in which five or six applications of the rays for ten minutes sufficed to cause depilation, with cure of the disease. In one of his cases the patient's chin and upper lip were covered by sycosis. This was rayed five times for periods of six to ten minutes, when the hair began to come out freely and the treatment stopped. A fortnight later the case was quite cured.

In another case, aged thirty-eight, there was coccogenic sycosis of seven months' duration. It commenced on the upper lip, and the affected area included the upper lip, the chin, the side of face, and part of scalp. The patient was rayed seven times, the last exposure being on April 25. By May 13 there was complete epilation, and the disease was cured without any further application.

Copper electrolysis can also be employed in sycosis. W. J. Morton† in 1898 reported the successful treatment by electrolysis of a case of sycosis by using a copper needle to puncture the affected spots, and this I can confirm from my own experience. Zinc is probably as effective as copper or better. Zinc electrolysis without puncture should be combined with needling of the suppurating follicles, in order to prevent the implication of neighbouring parts.

363. **Boils and Carbuncles.**—These can be well treated by zinc ionization. A zinc needle is the best method. Leduc‡ states that he has treated five cases of carbuncle of the neck by zinc ions, and has observed a remarkable effect in cutting short the disease. He advises a puncture of the carbuncle to its base with a tenotomy knife, and the introduction of a zinc needle. By proceeding gradually, the current is raised to thirty milliampères and allowed to pass for half an hour. After the application, the pain of the carbuncle at once begins to decrease, and in two days all inflammation has disappeared, leaving only the small orifice by which the needle was inserted. All the five cases were large boils or carbuncles, but none were in diabetic patients.

He further adds that two of his cases had been much troubled by boils of the neck for a long time.

In these cases, after the healing of the carbuncle, he applied

* *Medical Electrology and Radiology*, July, 1906.
† "Cataphoresis," by W. J. Morton. New York, 1898.
‡ *Archives d'Électricité Médicale*, 1910, p. 93.

zinc ionization with a pad moistened with a hot solution of zinc sulphate, and gave twenty milliampères for half an hour. After the next day all the small boils had disappeared. Marques has reported a similar case of multiple boils of the neck, and one of the forearm, cured quickly by the same procedure.

Coyle has reported a good effect upon carbuncles by X-ray treatment, and Cirera Salse of Barcelona from high-frequency applications.

364. **Acne.**—Various electrical treatments may be used for acne. The vacuum electrode of high-frequency produces a mild cutaneous reaction which is sufficient to cure the slighter cases. Ionization with salicylic ions has been recommended by Blanc,* who states that it has a great effect in improving the texture of the skin, particularly of the face, by the disinfection of the sebaceous glands.

X rays may also be used, but care is very necessary in treating the face, and the dose given should be less than a Sabouraud dose. Even so, the eyebrows should be protected, as well as those parts of the skin which do not need the treatment. The first effect of X rays may be to increase the inflammation in the acne pustules.

The dilated veins and redness of the nose, which is sometimes left behind by acne, may be treated by salicylic ions for the general redness, and by puncture with a fine needle for the visible vessels.

365. **Warts and Corns.**—The groups of warts which form upon the hands may be treated by electrolysis with magnesium ions. Two cases treated in this way under my own care were cured by one or two applications. In the first the warts were very numerous on the dorsum of the hand and the lower part of the forearm.

A circular pad of lint was applied to the back of the hand. It was moistened with a 5 per cent. solution of magnesium sulphate, and the current introduced by means of a carbon anode. A fortnight later the position of the pad could be distinctly traced upon the back of the hand, for the warts had entirely disappeared within that area, though they remained unaffected outside of it. In the second case, the warts on the back of a child's hand were removed by similar applications repeated twice. The control areas above and below the site of the pad

* *Semaine Médicale*, November 17, 1909.

were unaltered, and still presented many warts, while all those included in the electrolysis faded away completely within the following month.

Continental observers have obtained similar results. Some have found the continuous current answer equally well without the magnesium ions. In this case the ions penetrating would depend upon the salt used to moisten the pads, and upon the pole applied.

The most expeditious treatment for warts is ionization with a zinc needle. One milliampère for one minute is a sufficient application, unless they are large, in which case two transfixions at right angles to one another may be given, with the same current to each. I have treated many cases of warts on the hands, the soles of the feet, the scalp, and the face in this way, and with uniform success.

For the softer warts of the penis and the vulva percutaneous ionization without a needle is better, as it is less painful. Zinc usually answers well. but mercuric chloride may be used for warts of syphilitic persons and for condylomata. With mercury ions a carbon anode should be used. Corns may be treated in the same way as warts, and should be well soaked beforehand by a compress of zinc sulphate, of a strength of 1 per cent., to facilitate penetration of the current. A wart is undoubtedly due to an infection, which appears to reside in the lower layers of the epidermis, and the zinc needle should be kept at that level, being of less utility if it penetrates into the true skin or subcutaneous tissue. Corns are probably also due to an infection attacking what would otherwise be a harmless and painless callosity, and zinc appears to have a specific action in both cases, as also does magnesium—at least, in certain kinds of warts.

366. **Alopecia Areata.**—High-frequency applications with the vacuum electrode are useful in a general way to stimulate the growth of hair, and have been found to do good in cases of ordinary alopecia areata.

When there is reason to suspect the presence of some parasitic infection—as, for instance, when the disease attacks more than one member of a family—an ionization of the affected patches with a copper or a zinc anode is valuable. Such an application has a parasiticide effect, and each patch, together with a surrounding zone, should be treated once in this way. At a later period the stimulating effect of high-frequency spark discharges from

a vacuum electrode may be used to promote the rate of growth of the new hair.

A solution of copper sulphate at 1 per cent., or of zinc sulphate at 2 per cent., on several layers of lint, applied for fifteen minutes with a current of 2 or 3 milliampères per square centimetre, is a suitable application.

The condenser spark-lamp or iron electrode arc-lamp (§ 99) has been used with advantage in the treatment of alopecia areata. Kromayer,* dealing with this treatment, points out that when the skin is exposed to the light for a short time—for example, three minutes—a reddening of the skin appears, and may last for days, and he attributes the success of the applications to the hyperæmia produced by them. During fifteen months Kromayer had had six cases of alopecia under his care which had previously been treated without effect by various drug applications, and finally were subjected to treatment by ultra-violet light. All these cases were extensive and severe, and two were instances of total alopecia. In one of the two the light treatment was carried out from February 25 to May 12, in fifteen sittings of from half an hour to three-quarters of an hour duration. Each portion of the scalp was exposed to the light for four minutes. The reaction was well marked. The principle followed was to produce the reaction, and keep it up for fourteen days; then to pause until the result could be determined, and eventually to repeat the whole process. When seen in June, the patient was found to have hair over the whole scalp, and in some parts the growth was quite luxuriant. The other five were treated in a similar manner, and one was completely cured after one treatment cycle, one after three cycles, one after six. The Kromayer quartz mercury vapour lamp would now be used for these cases (Fig. 99).

Delpratt Harris† has reported nine cases, with six cures, from the use of Kromayer's method, the light being obtained from the condenser spark-lamp worked from a 10-inch coil.

367. **Pruritus.**—In pruritus of the anal and pudendal regions X rays have been very successful, and a course of ten or twelve applications at intervals of one or two weeks are sufficient to cure most cases. The patients frequently report that the itching is aggravated for a few hours immediately after the exposure to

* *Deutsche Medizinische Wochenschrift*, July 28, 1904.

† *Lancet*, July 6, 1912.

the rays, but when this has passed off the condition becomes comfortable, until after a few repetitions of the rays the pruritus disappears altogether.

The best arrangement of the patient is upon an ordinary radiographic couch, in a sitting position. This tends to flatten the region treated, and its limits can be circumscribed by the usual diaphragm on the tube-box. In this method there is no exposure of the patient, and the chances of dermatitis of the buttock or thighs are much reduced. In the male the scrotum can easily be shielded. Fractional doses once a week are better than full doses at intervals of three weeks.

The effluve of high-frequency, or applications with a glass vacuum electrode, also act favourably in many of these cases of pruritus.

Ionization has also proved useful, and particularly so with iodine ions. Horsfall has recommended urotropin by the mouth in 10-grain doses thrice daily, and says he has found it to be of extraordinary value.

368. **Eczema.**—X rays are of value in many forms of chronic eczema. The exudation tends to disappear, the itching quickly goes, and the crusts and scales are shed, and do not form anew. Many writers have noticed these striking results of X-ray applications. Belot states that he has obtained a complete cure of the local lesions in cases of eczema, and advises the administration of a single moderate dose, followed by a repetition after the lapse of eight or ten days. For a chronic patch of eczema, with thickening and infiltration of the skin, a single full dose equal to that employed in ringworm may be given. He points out, very properly, that, although radiotherapy cannot replace careful regimen and hygiene, it has a special value by being efficacious in certain forms of chronic eczema which are particularly rebellious to other local treatment.

369. **Psoriasis.**—This condition also reacts favourably to X rays, but recurrence is the rule. Marques* has reported the case of a man twenty-five years of age who had suffered from psoriasis of a pronounced type of the hands, elbows, back, chest, and knees, for four years, despite treatment by numerous medicaments. X rays were applied at first to the hands. A soft tube was used, with the antikathode at a distance of 6½ inches, the exposure being for five minutes on the dorsum and five minutes on the

* *Archives d'Électricité*, 1905, p. 163.

palms of the hands. Treatment was given every two or three days. After two weeks the sound skin was decidedly erythematous, but the scales were falling off, and the intolerable itching had entirely disappeared. This was all the treatment required for the hands.

Other affected regions were then subjected to similar treatment, and with the same success. Five months after the end of the course of treatment, which had taken only a month and a half in all, there had been no recurrence. The static breeze and high-tension effluvia had previously been tried in this case without any effect.

In a case of my own a chronic psoriasis of seven years' standing was much relieved by X-ray applications. The patient had very numerous spots and patches of psoriasis upon the trunk, limbs, and scalp. When seen a year later, the patient still had patches of psoriasis, but considered that some permanent effect had been gained by the X-ray treatment, and that the general tendency to psoriasis had been lessened.

Single patches of chronic psoriasis limited to definite situations are more favourably influenced by the X rays than those forms in which the psoriasis appears irregularly in numerous regions.

370. **Scars and Keloid.**—X rays are useful in keloid, and a fair number of successful cases have been reported. Moseley has reported the case of a man thirty-five years of age, who in 190[illegible] had a nævus of the right cheek removed. A keloid appeared, and on February 15, 1903, the patient presented a keloidal mass about 4 inches long running downward and forward on the cheek. In all twelve treatments were given, extending from February 15 to May 19, exposures to the X ray being of ten minutes' duration and employed three times a week. On May 15 an erythema began to appear, the skin became inflamed, and the keloid commenced to flatten.

Barnum* advises the use of a high tube, and exposures made at a distance of 15 to 20 inches for fifteen to twenty-five minutes on alternate days, until eight or ten applications have been given, and adds that treatment must be stopped at the first sign of reaction in the neighbouring healthy skin. He recounts three cured cases of extensive keloid.

Sir Malcolm Morris* has published instances of success from

* *Archives of Physiological Therapeutics*, 1906, vol. i., p. 170.

the use of Finsen light, and high-frequency applications have also been employed. Morris points out that the production of a local reaction appears to be the essential thing to be aimed at in treatment of keloid.

Radium applications have also been successful.

Chlorine ionization is the best mode of treatment of thickened scars, such as are formed after cases of severe burn. I have seen very good cosmetic results follow this method.

371. **Hyperidrosis.**—X rays can be used to arrest excessive sweating. They appear to act by impairing or destroying the sweat glands. Pirie† has reported a number of cases, most of which were successful. Epilation doses are needed in the case of the armpits, and care must be taken to shield surrounding parts. For the hands and feet four repetitions of a pastille dose at monthly intervals appear to suffice. Pirie expresses the opinion that the axillæ will stand more than a pastille dose.

372. **Chronic Ulceration.**—In the treatment of chronic ulcers of the legs X rays are frequently employed. Zinc ionization is perhaps a better mode of treatment. Doyle‡ states that he had obtained good results with ionic medication which were superior to those he had observed with any other mode of treatment. Finzi§ has also studied the effect of ionic treatment upon these ulcers, and has obtained good results. He mentions that one ulcer of ten years' standing healed after a single application, the healing process taking eight weeks. No other applications were used, except vaseline, and the patients continued at work. He compared zinc with copper by treating one half of an ulcer with each, and found that the part treated with zinc ions healed much more quickly than that to which copper was applied. He also compared the results with different strengths of current, and found the best results to follow applications at the strength of 2 to 3 milliampères per square centimetre for from two to four minutes.

I have had many instances of the healing of various kinds of chronic ulcer after ionization with zinc, and consider it to be a

* *Practitioner*, December, 1905.

† *British Medical Journal*, August 27, 1910; *Lancet*, August 12, 1911.

‡ Transactions of the Australian Medical Congress, vol. iii., October, 1908.

§ Proceedings of the Royal Society of Medicine, vol. ii. (Electrotherapeutic Section), p. 140.

valuable method. It should prove useful in some of the specific forms of ulceration which occur in tropical countries.

373. **Lupus Vulgaris.**—The famous work of Finsen in the treatment of lupus by concentrated light excited widespread interest, and stimulated others to attempt the cure of the disease by other physical methods, among which the X rays have perhaps been most extensively used. X-ray treatment has the advantage that it can be employed over a much larger area at a time than is possible with Finsen light, and this tends to reduce the time consumed during the treatment—an important consideration in many cases.

Malcolm Morris and Dore* consider that the X rays can best be employed as a preliminary in cases in which there is extensive ulceration. The effect of the X rays in bringing about rapid healing of ulceration has, in their experience, been so marked that they look upon ulceration as a definite indication for their use. When the ulceration is superficial, healing may occur over a mass of deep-seated lupus, and subsequent breaking down is then likely to occur.

X rays may be used with advantage as a preliminary to Finsen-light treatment.

The same writers consider that, although the immediate effects of X-ray treatment, especially in cases in which there is extensive ulceration, are so good, their experience has been that the initial rapidity of improvement is, unfortunately, not maintained. Secondary conditions (ulceration, discharge, and œdema) are relieved almost at once; but in respect of eradication of the disease, progress is disappointingly slow, and failure is not infrequent. Opinions differ as to the possibility of entirely destroying the granulomatous tissue. Many cases have been reported in which nodules have remained after long-continued treatment. In non-ulcerative lupus the results seem to be less satisfactory as regards complete destruction of the foci of diesase.

In the case of lupus high-frequency applications may have a beneficial action. Chisholm Williams, Hall-Edwards, and others, have written on this point.†

The treatment may be applied by the ordinary brush effluve; or by means of a vacuum electrode. It is thought that these electrodes should show a green fluorescence, giving evidence of

* *British Medical Journal*, June 6, 1903.

† *Ibid.*, October 24, 1903, p. 1061.

the presence of X rays. General electrization by auto-condensation may be combined with the local applications.

High-frequency currents applied with a small glass vacuum electrode are a very convenient way of treating lupus in the nostril or in any other region difficult of access.

Ionization is also useful in the treatment of lupus, and Stopford Taylor and MacKenna* have described a mode of procedure which they consider very satisfactory in the treatment of the nodules of lupus. The part is first rubbed over with a pledget of cotton-wool soaked in liquor potassæ, which denudes the nodules of their epithelial covering, leaving them as gelatinous masses embedded in the skin. The part is then wiped free of the alkali, and ionized with a 2 per cent. solution of zinc chloride or a 10 per cent. solution of the sulphate to moisten the pad covering the part. The usual current of 2 or 3 milliampères per square centimetre is applied, and given for ten or twenty minutes. The authors state that after the application every lupus nodule is found converted into a dry, glazed, whitish plug. Considerable redness and swelling follow; serum exudes and forms a crust, which falls in about a fortnight. Some nodules are then found to have disappeared; others have diminished in size. Treatment should be renewed every fortnight until all have disappeared. The ultimate result is a smooth elastic scar. For cases in which the nodules are discrete they find the treatment superior to others in speed and efficacy. When extensive ulcerations have been healed by X rays or Finsen light, and nodules persist, these may well be treated by the zinc ionization.

Another ionic method of treating lupus is to use iodides given internally, and then to set free nascent iodine in the part to be treated. This is effected by applications of ozone or of hydrogen peroxide to the ulcerated part, or by the use of an electrolytic needle made the anode of the circuit. The use of ozone for the purpose has been mentioned in § 84.

As the action of the iodine set free by ozone or hydrogen peroxide is a superficial one, an attempt was made by Axel Reyn† to obtain a liberation of iodine deeper down in the tissues by the electrolytic needle. After the administration of from 30 to 40 grains of sodium iodide by the mouth, a recognizable amount of iodine is set free around the needle inserted into the tissues.

* *Liverpool Medico-Chirurgical Journal*, January, 1911.

† *Berliner Klinische Wochenschrift*, No. 42, 1911.

The strongest reaction is obtained an hour and a quarter or two hours after the dose of iodide has been taken. Reyn has treated five patients in this way with very quick and favourable results. In two the disease completely disappeared; in all there was improvement. In no case was there necrosis of tissue. A dose of 3 or 4 milliampères for three minutes is mentioned. A group of five needles combined in a holder has been used to cover a larger area, but probably five separate punctures with one needle would be better. The needle must be of platinum or platinum iridium alloy.

374. **Lupus Erythematosus.**—This condition is difficult to treat successfully. Some cases respond satisfactorily, but others remain unchanged or may even seem to grow worse under treatment. This is the case with X rays, with Finsen light treatment, and with high-frequency applications. Temporary amelioration, however, is not uncommon with all these methods.

Ionization with zinc has also been tried, and successes have been reported, but in general the improvement is temporary. Freezing with solid CO_2 seems to be a promising method.

375. **Ichthyosis.**—Leduc has reported the case of a boy of twelve, whose body since infancy has been covered with brownish-black scales, which desquamated and were renewed incessantly. Every form of treatment, both for the condition of the skin and his general health (which was precarious), proved useless. On April 4, 1905, an exposure of X rays was made with a low tube, the antikathode being 40 centimetres from the part treated. The head, trunk, and limbs were successively exposed for a total period of twelve minutes. A fortnight later the boy appeared better, desquamation had been abundant, but the scales had not recurred, and islets of white skin could be seen. A second exposure, similar to the first, was given on April 19, when continued improvement was observed. His general health was better, and he was growing and putting on flesh. A third exposure was given on May 8. On June 8 almost all the skin appeared normal; there were only a few small scaly patches on the ears, arms, and legs. A fourth exposure was then given, and in July the whole of his skin was normal, and his general condition very satisfactory.*

376. **Mycosis Fungoides.**—This uncommon disease has proved to be amenable to X-ray treatment, and many successful cases

* *Archives d'Électricité Médicale*, September 10, 1905.

have been published. Stopford Taylor has reported the following case :*

"The patient, a man aged forty-seven years, first noticed a reddish, painless lump of the size of a walnut over the middle of the spine in January, 1903. He did not apply any remedies, and after two or three months the lump disappeared. Before its disappearance five small similar tumours appeared over his left ribs. They never attained a larger size than that of a bean, and went away spontaneously about the same time as the large lump. For about twelve months he enjoyed good health, and saw no more tumours. At the end of that time there appeared scattered over his back a number of painless, reddish lumps of various size, which were freely movable. So far as the patient observed, his general health did not seem to be affected by them. The tumours grew slowly but steadily. In December, 1905, there were scattered over his back a number of tumours of varying size; three of these were large, the largest being of about the size of a duck's egg. Large areas of the adjacent skin showed the premycotic condition, which in this case was of the erythematous type, one large disc being very distinct. One of the smaller nodules was removed for the purposes of histological examination, which was made by Dr. F. P. Wilson. On cutting into the tumour, it appeared to the naked eye as a round mass, much denser and firmer than the surrounding tissue, and sharply marked off from it. Microscopical examination showed a mass of densely packed cells in the corium. The cells consisted of connective-tissue cells of various shapes, numerous small round cells, and a few plasma cells. No mast cells were found. In some parts the cells were less deeply stained and were crenated in appearance; granular débris was scattered between them. In some parts of the specimen, especially round the periphery, the cells were arranged in columns. Outside the limits of the main mass foci of cells were scattered through the corium. The epidermis was thinned, and its interpapillary processes flattened out; there was intercellular œdema.

"Treatment by the X rays was given, with exposures of ten minutes' duration twice a week, at a distance of 9 inches from the antikathode, 0·5 Holzknecht's units being administered at each sitting, with rays of penetration 7 on Benoist's scale. In all, fifteen exposures were given. The facility with which the

* *Lancet*, March 24, 1906.

tumours yielded to the treatment was remarkable, since improvement was noticed after the third sitting, and they were completely level with the skin before the hair fell from the adjacent parts of the back."

Similar cases have been reported by numerous other writers.

377. **Guinea-Worm.**—Faulkner* has recorded a case of the treatment of this affection by electricity. Direct current was used, and one pole was held in the patient's hand, the other being applied to the protruding extremity of the worm; the application was continued for an hour with gentle traction, and at the end of that time the whole had been extracted. The usual process of gradually extracting a guinea-worm by traction for a few minutes daily is a very tedious affair, and may take weeks to complete, and the worm is often broken in the process. Faulkner's explanation of the action of the current is that the worm is benumbed and rendered incapable of resisting.

* *British Medical Journal*, 1883, ii. 1280.

APPENDIX

TABLE OF ELECTRO-CHEMICAL EQUIVALENTS EXPRESSED IN MILLIGRAMMES PER COULOMB (§ 25) AND PER MILLI-AMPERE MINUTE, AND OF THE RELATIVE VELOCITIES OF IONS DETERMINED BY PROFESSOR S. LEDUC FOR THE TISSUES OF THE BODY.

THE VELOCITIES OF THE ANIONS ARE COMPARED WITH CHLORINE, THOSE OF THE KATHIONS WITH POTASSIUM (SEE PAGE 309).

	Milligrammes per Coulomb.	Milligrammes per Milliampere Minute.	Velocities.
Anions :			
Bromine	0·82	0·049	0·9
Chlorine	0·3675	0·022	1·0
CO_3	0·32	0·019	0·84
Hydroxyl	0·18	0·01	1·27
Iodine	1·31	0·078	1·16
NO_3	0·66	0·04	0·7
PO_5	0·26	0·016	1·18
Salicylic acid	1·4	0·085	—
SO_4	0·5	0·029	0·[illegible]8
Kathions :			
Ammonium	0·06	0·003	·56
Calcium	0·206	0·012	0·5
Cocaine	3·0	0·18	0·59
Gold	0·678	0·04	1·22
Hydrogen	0·01	0·0006	0·88
Lithium	0·07	0·004	1·28
Magnesium	0·115	0·007	0·5
Mercury	1·03	0·062	0·8
Potassium	0·4	0·024	1·0
Quinine	3·9	0·234	0·62
Silver	1·1	0·06	0·5
Sodium	0·23	0·014	1·6
Strychnine	3·4	0·207	—
Sulphur	0·16	0·01	—
Zinc	0·33	0·02	0·6

LIST OF TOWNS AND PLACES, WITH PARTICULARS OF THEIR ELECTRIC LIGHTING SUPPLY.*

1. Provincial.

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Aberdare	D	230	—
Aberdeen	A	230	50
	D	220 & 230	—
Abertillery	D	250	—
Aberystwith	D	220	—
Accrington	A	230	50
	D	230	—
Airdie	A	220	25
	D	240	—
Aldeburgh	D	200	—
Alderley Edge	D	210	—
Aldershot	D	210	—
Alloa	D	220	—
Alnwick	D	230	—
Altrincham	A	100	80
Arbroath	D	250	—
Ascot	D	220	—
Ashington	D	230	—
Ashton-under-Lyne	A	250	50
	D	240	—
Atherton	A	240	50
Ayr	A	100 & 200	60
	D	250	—
Bacup	A	230	50
Banbury	D	230	—
Bangor	D	200	—
Barking	A	230	50
	D	230	—
Barnes	D	210	—
Barnet	D	230	—
Barnsley	D	230	—
Barnstaple	D	230	—
Barrow-in-Furness	D	220	—
Bath	A	100	100
	D	220	—

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Batley	D	220	—
Beauly	D	240	—
Beckenham	A	200	50
Bedford	A	105 & 210	60
Bedlington	D	230	—
[redacted]	D	220	—
Belturbet	D	110	—
Berwick	D	240	—
[redacted]	D	220	—
Bexley	A	200	50
Birkdale	D	230	—
Birkenhead	D	230	—
Birmingham	A	230	50
	D	220 & 240	—
Bispham	D	250	—
Blackburn	A	110 & 220	50
	D	220	—
Blackpool	A	200	83
Blaenau Festiniog	D	230	—
Blair Atholl	D	210 & 220	—
Blythe and Cowpen	D	230	—
Bolton	A	100 & 200	83
	D	230	—
Bo'ness	D	230	—
Bootle	D	220	—
Bournemouth	A	100 & 200	100
	D	220	—
Bovey Tracey	D	200	—
Bradford	A	230	50
	D	230	—
Bray	A	100 & 200	60

* This list is prepared from the tables published annually by *The Electrician* in January. They should be consulted by those in need of fuller information as to all details of the electric supply of the country. I take this opportunity of expressing my thanks to the Editor of that journal for his courteous permission to make use of them for this book.

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Brechin ..	D	240	—
Bridgend ..	A	200	60
Bridgwater ..	D	230	—
Bridlington ..	D	220	—
Brighouse ..	D	230	—
Brighton ..	D	115 & 230	—
Bristol ..	A	105 & 210	93
	D	250	—
Briton Ferry	A	220	50
Broadstairs ..	D	240	50
Bromley ..	D	210	—
Broughty Ferry	D	230	—
Brynamman	D	200	—
Buckingham	D	220	—
Bude	D	200	—
Buncrana ..	D	235	—
Burgess Hill	D	230	—
Burnley ..	D	220	—
Burslem ..	D	220	—
Burton-on-Trent ..	A	100 & 200	[illegible]
Bury	D	220	—
Bury St. Edmunds	D	200	—
Buxton ..	D	230	—
Caergwrle ..	D	100	—
Caldy ..	D	115	—
Calverley ..	A	230	50
Camborne ..	D	240	—
Cambridge ..	A	100 & 200	90
Cambuslang ..	D	250	—
Canterbury ..	D	220	—
Cardiff ..	A	200	40
	D	200	—
Carlisle ..	D	230	—
Carlow ..	D	200	—
Carmarthen ..	D	220	—
Carnarvon ..	D	230	—
Carshalton ..	A	200	50
Castleford ..	A	230	50
Caterham ..	D	240	—
Chagford ..	D	200	—
Charleville ..	D	220	—
Chatham ..	A	100 & 200	50
Cheam ..	A	200	50
Chelmsford ..	A	100 & 200	100
Cheltenham ..	A	100 & 200	100

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Chepstow ..	D	230	—
Chesham	A	200	50
	D	230	—
Chester ..	D	210	—
Chesterfield ..	D	240	—
Chichester ..	D	220	—
Chippenham	D	230	—
Chislehurst ..	D	210	—
Christchurch	D	250	—
Church Stretton	D	200	—
Clacton-on-Sea	D	230	—
Cleckheaton	D	230	—
Cleethorpes ..	D	230	—
Coatbridge ..	A	220	25
	D	240	—
Colchester ..	D	210	—
Colne ..	D	240	—
Colwyn Bay	D	220	—
Cork	D	230	—
Coventry ..	A	200	50
Cowes ..	D	240	—
Crewe ..	D	230	—
Cromer ..	D	240	—
Croydon ..	A	200	60
	D	230	—
Dalkeith	D	225	—
Darlington ..	D	230	—
Dartford ..	D	230	—
Dartmouth ..	D	240	—
Darwen ..	D	230	—
Dawlish ..	D	200	—
Denny ..	A	230	50
Derby ..	A	102 & 205	40
	D	230	—
Devonport ..	D	230	—
Dewsbury ..	D	220	—
Dollar ..	D	225	—
Doncaster ..	D	230	—
Dorking ..	D	240	—
Dover ..	A	100 & 200	100
Dublin ..	A	200	50
Dudley ..	D	230	—
Dukenfield ..	D	230	—
Dumbarton ..	D	240	—
Dumfries ..	D	230	—
Dundalk ..	D	110 & 220	—
Dundee ..	A	200	50
	D	200	—
Dunfermline	A	220	50

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Durham ..	D	240	—
East Barnet ..	A	240	50
Eastbourne ..	A	200	50
Ebbw Vale ..	D	230	—
Eccles ..	A	200	50
Edgware ..	A	240	50
Edinburgh ..	A	230	50
	D	230	—
Edmonton ..	A	240	50
Egham ..	A	100	50
Elland ..	D	240	—
Enfield ..	D	240	—
Epsom ..	D	230	—
Erith	A	200	50
Eton	A	220	50
	D	110 & 220	—
Exeter ..	A	100	60
Exmouth ..	D	225	—
Falkirk ..	A	230	50
	D	230	—
Falmouth ..	D	240	—
Fareham ..	A	105 & 210	50
Farnham ..	A	100	50
Farnworth ..	D	220	—
Farsley ..	A	230	50
Faversham ..	D	230	—
Felixstowe ..	D	200	—
Finchley ..	D	250	—
Fladbury ..	D	220	—
Fleetwood ..	D	200	—
Folkestone ..	D	210	—
Frinton ..	D	230	—
Frome ..	D	240	—
Galway ..	D	125	—
Gateshead ..	D	240	—
Gillingham ..	A	100 & 200	50
	D*	220	—
Glasgow ..	D	250	—
Glossop ..	D	240	—
Gloucester ..	D	220	—
Godalming ..	D	240	—
Gomersal ..	A	230	50
Goring ..	D	100 & 210	—
Gorseinon ..	D	200	—
Gosport ..	D	240	—
Govan ..	D	250	—
Grangemouth	A	250	50
Grantham ..	D	240	—
Grassington ..	D	230	—
Gravesend ..	D	230	—
Grays ..	D	230	—
Greenock ..	A	110 & 220	50
	D	250	—
Greystones ..	A	100	50
Grimsby ..	D	230	—
Guernsey ..	D	210	—
Guildford† ..	D	215	50
Halifax ..	D	230	—
Hamilton ..	D	240	—
Hanley ..	A	100 & 200	100
Harrogate ..	A	100 & 200	50
Harrow ..	D	220	—
Hartlepool ..	D	230	—
Haslemere ..	A	100	50
Haslingden ..	A	230	50
Hastings ..	A	200	100
Hawick ..	D	240	—
Hebben Bridge	D	240	—
Hebburn ..	D	230	—
Heckmondwike	D	230	—
Hendon ..	A	240	50
Hereford ..	D	220	—
Hertford ..	D	230	—
Heston ..	D	240	—
Hexham ..	A	120 & 220	40
Heywood ..	D	200	—
Hindhead ..	D	220	—
Hipperholme	A	230	50
Hitchin ..	D	240	—
Holyhead ..	D	200	—
Honiton ..	D	200	—
Honley ..	D	200	—
Hornsey ..	D	240	—
Horsforth ..	A	230	50
Horsham ..	D	230	—
Houghton-le-Spring ..	A	220	40
Hove ..	D	220	—
Hoylake ..	A	230	50
Huddersfield	A	100 & 200	50
Hull	D	220	—

* Special supply to Royal Naval Hospital.
† Also A. C. 220, 50 periods to village of Shalford.

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Ilford ..	D	230	—
Ilfracombe ..	D	240	—
Ilkeston ..	D	230	—
Ingleton ..	D	100 & 200	—
Inverness ..	D	240	—
Ipswich ..	D	230	—
Isleworth ..	D	240	—
Ivybridge ..	D	200	—
Jarrow ..	D	240	—
Jedburgh ..	D	225	—
Keighley ..	D	230	—
Kendal ..	D	220	—
Keswick ..	A	100	100
Kettering ..	D	230	—
Keynsham ..	D	230	—
Kidderminster	D	230	—
Kildare ..	D	200	—
Killarney ..	A	100	100
Kilmalcolm ..	D	240	—
Kilmarnock ..	D	240	—
Kilpatrick ..	A	230	25
Kingsbury ..	A	240	50
King's Lynn	D	200	—
Kingston-on-Thames	A	105	77
Kirkcaldy ..	D	230	—
Lancaster ..	D	230	—
Larne ..	A	110 & 220	100
Launceston ..	D	200	—
Leamington ..	D	230	—
Leatherhead	A	220	50
Leeds ..	D	220	—
	A	100 & 200	50
Leek	D	230	—
Leicester ..	A	100 & 200	50
Leigh.. ..	D	220	—
Leith.. ..	D	230	—
Leominster ..	D	230	—
Letchworth ..	D	250	—
Lewes ..	D	230	—
Leyton ..	D	150	—
Limavady ..	A	110 & 220	100
Limerick ..	D	230	—
Lincoln ..	D	230	—
Littleborough	A	230	50
Liverpool ..	D	220	—
Liversedge ..	A	230	50
Llandilo ..	D	230	—

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Llandrindod..	D	230	—
Llandudno ..	D	220	—
Llanelly ..	D	250	—
Llangollen ..	D	220	—
Llanrwst ..	D	220	—
Londonderry	D	220	—
Long Eaton ..	D	220	—
Longton ..	D	230	—
Loughborough	D	220	—
Lowestoft ..	D	230	—
Ludlow ..	D	230	—
Luton ..	D	250	—
Lymington ..	D	240	—
Lynmouth ..	A	100	100
Lynton ..	A	100	100
Maghera ..	D	220	—
Maidenhead ..	D	230	—
Maidstone ..	D	230	—
Malden ..	A	220	50
Malton ..	D	230	—
Malvern ..	A	100 & 200	50
Manchester ..	A	240	50
	D	100, 200 & 250	—
Mansfield ..	D	240	—
Mardy ..	D	220	—
Margate ..	D	240	—
Market Drayton	D	240	—
Melksham ..	D	100	—
Melrose ..	D	225	—
Melton Mowbray	D	240	—
Menai Bridge	D	220	—
Merthyr Tydvil	A	250	85
Mevagissey ..	D	110	—
Mexborough	D	230	—
Middlesbrough	D	220	—
Middleton ..	D	220	—
Milford-on-Sea	D	230	—
Minehead ..	A	110 & 220	50
Mirfield ..	D	220	—
	A	100 & 200	50
Monkseaton	D	240	—
Monmouth ..	A	100 & 200	60
Montrose ..	D	240	—
Morecambe ..	D	220	—

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Morley	A	100 & 200	60
Morpeth	D	230	—
Motherwell	D	230	—
Mountain Ash	A	230	25
Musselburgh	D	230	—
Neath	A	220	50
Nelson	D	230	—
Neston	D	230	—
Newbury	D	240	—
Newcastle Emlyn	D	110	—
Newcastle-on-Tyne	A	100	80
	D	240	—
Newcastle-under-Lyme	D	230	—
Newmarket	D	210	—
Newport (I.W.)	D	240	—
Newport (Mon.)	A	100 & 200	87
	D	230	—
Newquay	D	230	—
Newton Abbott	D	240	—
Northallerton	D	220	—
Northampton	D	210	—
Northfleet	D	230	—
Northwich	D	220	—
Northwood	D	240	—
Norwich	D	220	—
Nottingham	D	200	—
Nuneaton	D	220	—
Oban	D	230	—
Ogmore Valley	D	220	—
Oldham	D	210	—
Oswestry	D	220	—
Oulton	D	230	—
Oxford	D	100	—
Paignton	D	220	—
Paisley	A	200	50
Pangbourne	D	240	—
Pembroke (Ireland)	D	220	—
Penarth	D	230	—
Penge	A	100 & 200	50
Penrith	D	110 & 220	—
Perth	D	230	—
Peterborough	D	200	—
Plymouth	A	100 & 200	50
Plympton	D	200	—
Pontypool	D	100	—
Pontypridd	D	230	—
Porlock	D	200	—
Portpatrick	D	200	—
Portsmouth	A	100 & 200	50
Prescot	A	100	100
	D	250	—
Preston	A	220	50
	D	220	—
Pudsey	D	230	—
Queenstown	D	230	—
Radcliffe	A	230	50
Ramsbottom	A	230	50
Ramsgate	D	240	—
Rathmines	D	220	—
Rawtenstall	A	230	50
	D	230	—
Reading	A	200	50
	D	200	—
Redditch	A	200	70
Redruth	D	240	—
Reigate	A	200	50
Rhyl	D	230	—
Rhymney	A	230	25
Richmond	D	220	—
Rochdale	D	220	—
Rochester	A	100 & 200	50
Ross	D	230	—
Rotherham	A	230	50
	D	230	—
Rothesay	D	250	—
Roundhay	D	230	—
Rugby	A	220	50
Ruislip	D	240	—
Runcorn	A	250	50
Rutherglen	A	230 & 250	25
Ryde	D	240	—
St. Albans	D	230	—
St. Andrews	D	225	—
St. Anne's-on-Sea	D	240	—
St. Austell	D	110 & 220	—
St. Helens	A	230	50
	D	230	—
Sale	D	230	—
Salford	A	200	75
	D	220	—
Salisbury	D	210	—
Saltburn	D	220	—

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Sandown ..	D	240	—
Scarborough	A	100 & 200	80
Shanklin ..	D	240	—
Sheerness ..	A* D	220* 230	50 —
Sheffield ..	A	200	50
Shildon ..	D	230	—
Shipley ..	D	230	—
Shrewsbury ..	D	210	—
Sidcup ..	A	100 & 200	50
Sleaford ..	D	220	—
Slough ..	D	220	—
Smethwick ..	A D	110 250	25 —
Southampton	D	200	—
Southend ..	D	230	—
Southgate ..	A	240	50
Southport ..	A	110 & 220	50
South Shields	A	110 & 220	50
Sowerby Bridge	A	230	50
Spennymoor ..	D	230	—
Stafford ..	D	210	—
Stalybridge ..	D	230	—
Stamford ..	D	240	—
Stirling ..	D	230	—
Stockport ..	D	230	—
Stockton-on-Tees	D	230	—
Stoke-on-Trent	D	240	—
Stratford-on-Avon	D	220	—
Stretford ..	D	220	—
Sunderland ..	D	220	—
Surbiton ..	D	240	—
Sutton ..	A	200	50
Sutton Coldfield	D	230	—
Swansea ..	A D	220 220	50 —
Swindon ..	D	220	—
Swinford ..	D	220	—
Swinton ..	D	250	—
Tadcaster ..	D	230	—
Taunton ..	A	105 & 210	60
Tewkesbury ..	D	230	—
Thirsk ..	D	230	—
Todmorden ..	D	230	—
Tonbridge ..	D	220	—
Tonyrefail ..	A	220	50
Topsham ..	D	100	—
Torquay ..	A	200	50
Totnes ..	D	225	—
Trowbridge ..	A	230	—
Tunbridge Wells	A	220	68
Turton ..	A	230	50
Twickenham	A D	240 240	50 —
Tynemouth ..	D	220	—
Uxbridge ..	A	200	50
Ventnor ..	D	210	—
Wadebridge ..	D	135	—
Wakefield ..	A	200	60
Wallasey ..	A	100 & 200	50
Walsall ..	D	105 & 210	—
Walthamstow	D	230	—
Walton ..	D	240	—
Walton-on-the-Naze	D	200	—
Warrington ..	A D	220 230	— —
Warwick ..	D	230	—
Watford ..	A	200	50
Wedmore ..	D	230	—
Wednesbury	D	230	—
Wellingboro'gh	D	230	—
West Bromwich	D	230	—
West Hartlepool	D	230	—
West Houghton	A	230	50
Weston-super-Mare	D	230	—
Weybridge ..	D	240	—
Weymouth ..	D	230	—
Whitby ..	D	230	—
Whitchurch (Hants)	D	240	—
Whitchurch (Glam.)	A	230	25
Whitehaven	D	210	—
Whitley ..	D	240	—
Whitwood ..	A	220	50

* In Queenborough.

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Widnes ..	A	250	50
Wigan ..	D	230	—
Wilmslow ..	D	210	—
Wimbledon ..	A	220	50
Winchester ..	D	210	—
Windermere ..	A	100	100
Windsor ..	A	220	50
	D	110 & 220	—
Wishaw ..	D	240	—
Witney ..	D	220	—
Woking ..	A	200	100
Wolverhampton	D	220	—
Woolwich ..	D	210	—
Worcester ..	A	100	50
	D	200 & 230	—
Worksop ..	D	220	—
Wormit ..	D	230	—
Worthing ..	D	230	—
Wrexham ..	D	230	—
Wycombe ..	D	210	—
Yarmouth ..	A	100 & 200	83·5
York	D	230	—
Ystradgynlais	D	220 & 240	—

2. London and District.

The supply to the central parts of London is difficult to state concisely, as the areas of supply of the following companies overlap considerably. On the Surrey side the overlap is especially confusing.

Company.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Brompton and Kensington	A	100	83
Charing Cross and Strand	D	100 & 200	—
Ditto, City area	D	200	—
City of London (Southwark)	A	102 & 204	100
	D	204	—
Co. of London	D	215	—
(Bloomsbury, Finsbury and Holborn[p'ts])	A	104	50
(Bermondsey, Camberwell, and Wandsworth[parts])	A	205	50
(Southwark [parts])	D	205	—
Kensington and Knightsbridge	D	200	—
London Electric	A	105 & 210	85
	D	230	—
Metropolitan Electric	A	100 & 200	60
	D	100 & 200	—
Smithfield Markets	D	100 & 200	—
South London Electric	A	220	50
South Metropolitan	A	100 & 200	50
St. James's and Pall Mall	D	110 & 220	—

In general the names of these companies indicate their areas.

The London Electric Supply distributes in parts of Bermondsey, Camberwell, Chelsea, Deptford, Greenwich, Southwark, and Westminster. The Metropolitan in Paddington, in Central London, south of Oxford Street, and on both sides of Holborn. The South London Electric Supply Corporation in Kennington, Stockwell, Herne Hill, etc. The South Metropolitan Electric Light and Power Company in Blackheath, Catford, Deptford, Forest Hill, Lewisham, and Sydenham.

Place.	System: A, Alternating; D, Direct.	Pressure of Supply.	Periodicity of Alternating Supply.
Acton ..	D	230	—
Battersea ..	D	230	—
Bermondsey	D	205 & 240	—
Brentford ..	A	240	50
Chelsea ..	D	200	—
Chiswick ..	D	220	—
Ealing ..	A	105 & 210	40
East Ham ..	D	240	—
Finsbury ..	A	104	50
Fulham ..	A	200	50
Hackney ..	D	240	—
Hammersmith	A	110 & 220	50
Hampstead ..	A	105 & 210	90
Holborn ..	A	100, 104 & 200	—
Holborn ..	D	100 & 200	—
Islington ..	A	100 & 200	50
Kensington ..	D	200	—
Knightsbridge	D	200	—
Notting Hill ..	D	200	—
Poplar ..	D	230	—
St. Marylebone	D	240	—
St. Pancras ..	D	110 & 220	—
Shoreditch ..	D	240	—
Southwark ..	D	220	—
Stepney ..	D	240	—
Stoke Newington	D	240	—
Tottenham ..	A	240	50
West Ham ..	A	100 & 200	50
Westminster	D	200	—
Willesden ..	A	240	50
	D	240	—

DESCRIPTION OF PLATES

DESCRIPTION OF PLATES.

PLATES I.—VI.

The Motor Points.

PLATE

I. THE HEAD AND NECK.
II. THE UPPER LIMB (*back*).
III. THE UPPER LIMB (*front*).
IV. THE THIGH (*front*).
V. THE THIGH AND LEG (*back*).
VI. THE LEG AND FOOT (*outer side*).

PLATES VII.—XI.

The Cutaneous Nerves.

VII. THE HEAD AND NECK.
VIII. THE UPPER LIMB (*back*).
IX. THE UPPER LIMB (*front*).
X. THE LOWER LIMB (*front*).
XI. THE LOWER LIMB (*back*).

PLATES XII.—XIV.

The Segmental Distribution of the Sensory Nerve Roots.

XII. FRONT VIEW.
XIII. BACK VIEW.
XIV. SIDE VIEW.

PLATE I.

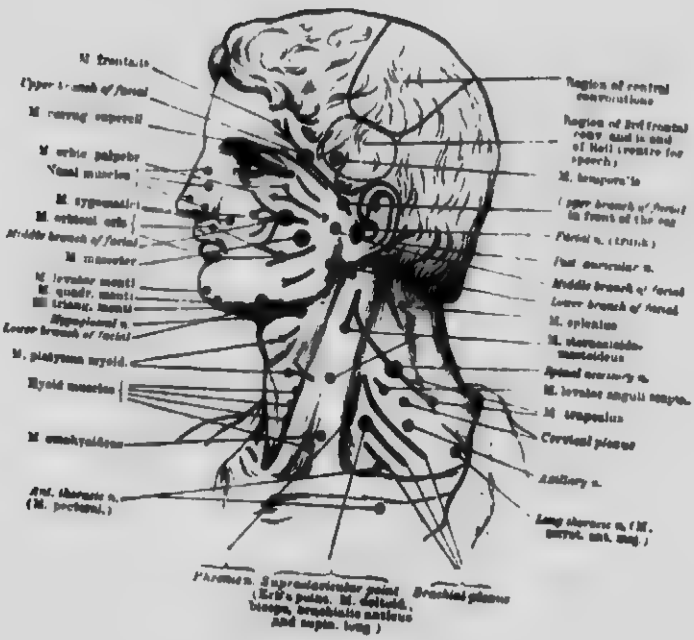
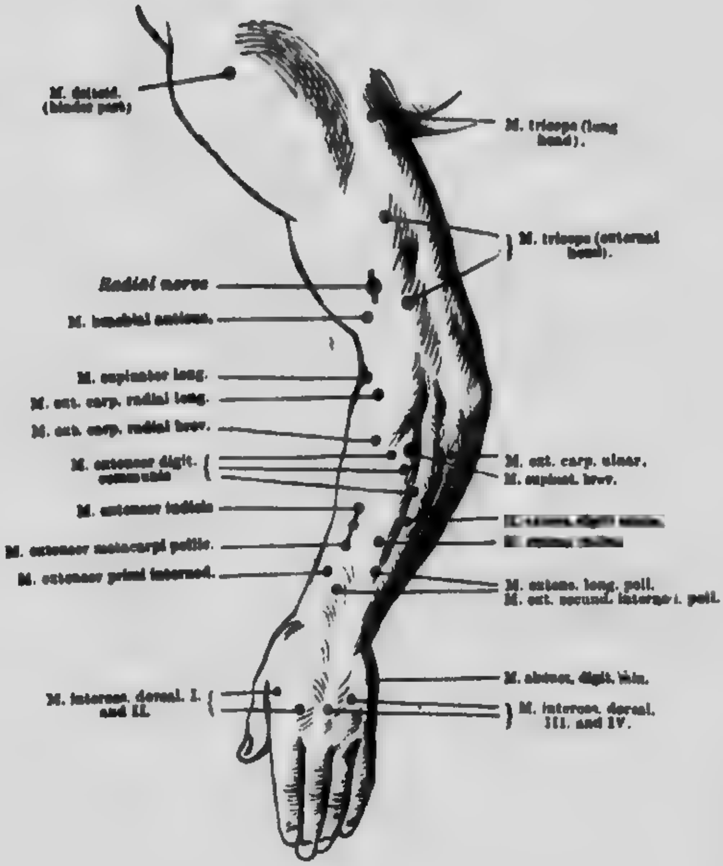

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n.
(M. pectoral.)
Region of central convolutions
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapu.
M. trapezius
Cervical plexus
Axillary n.
Long thoracic n. (M. serrat. ant. mag.)
Phrenic n.
Supraclavicular point
(Erb's point. M. deltoid, biceps, brachialis anticus and supin. long)
Brachial plexus

PLATE II.



M. deltoid. (hinder part)
M. triceps (long head).
M. triceps (external head).
Radial nerve
M. brachial anticus.
M. supinator long.
M. ext. carp. radial long.
M. ext. carp. radial brev.
M. extensor digit. communis
M. extensor indicis
M. extensor metacarpi pollic.
M. extensor primi internod.
M. ext. carp. ulnar.
M. supinat. brev.
[redacted]
M. extens. long. poll.
M. ext. secund. internod. poll.
M. abduct. digit. min.
M. inteross. dorsal. I. and II.
M. inteross. dorsal. III. and IV.

PLATE III.

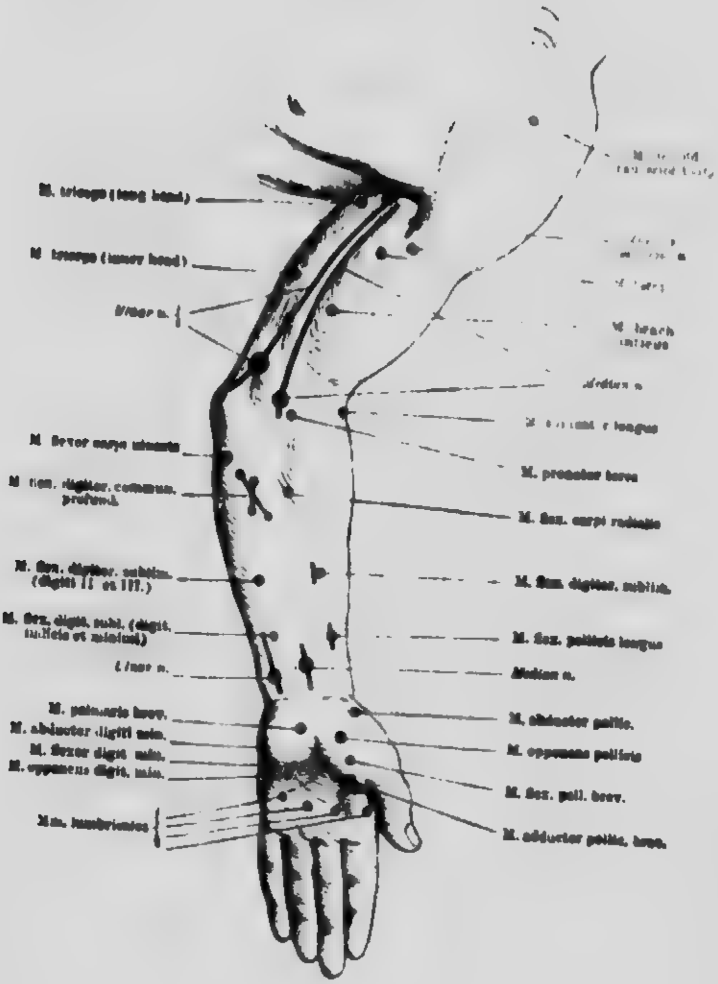

M. triceps (long head)
M. triceps (inner head)
Ulnar n.
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. digitor. sublim. (digiti II et III.)
M. flex. digit. subl. (digit. indicis et minimi)
Ulnar n.
M. palmaris brev.
M. abductor digiti min.
M. flexor digit. min.
M. opponens digit. min.
Mm. lumbricales
M. brach anticus
Median n.
M. pronator teres
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. pollicis longus
Median n.
M. abductor pollic.
M. opponens pollicis
M. flex. poll. brev.
M. adductor pollic. brev.

PLATE IV.

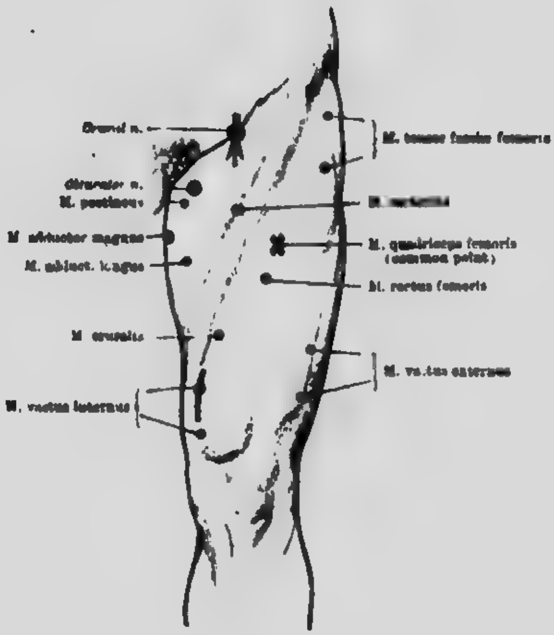

Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. quadriceps femoris
(common point)
M. rectus femoris

PLATE V.

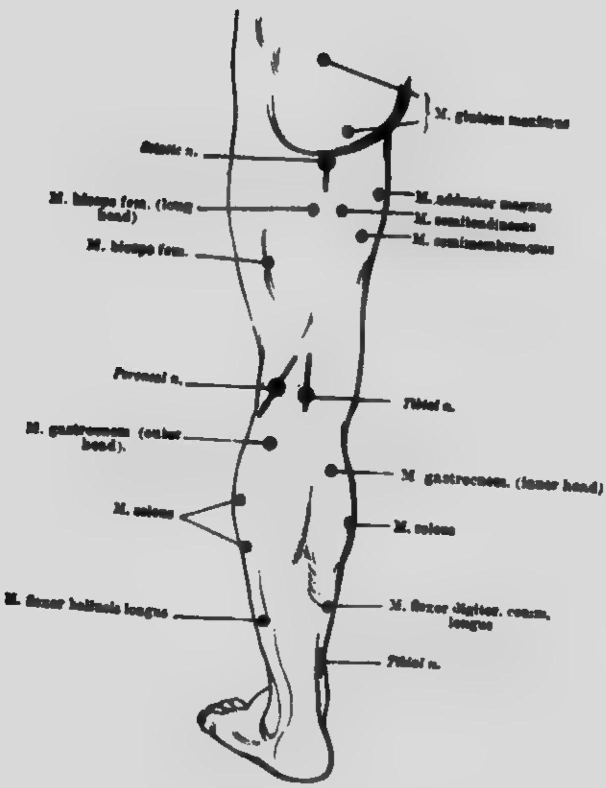

M. gluteus maximus
Sciatic n.
M. biceps fem. (long head)
M. adductor magnus
M. semitendinosus
M. semimembranosus
M. biceps fem.
Peroneal n.
Tibial n.
M. gastrocnem. (outer head).
M. gastrocnem. (inner head)
M. soleus
M. soleus
M. flexor hallucis longus
M. flexor digitor. comm. longus
Tibial n.

PLATE VI.

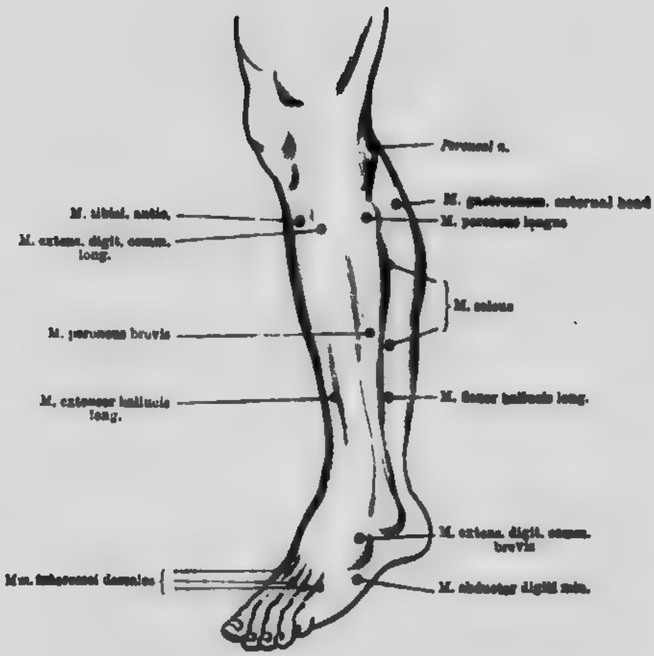
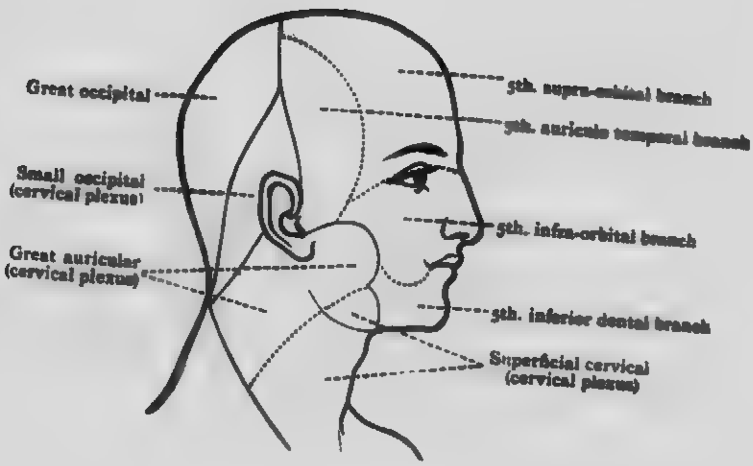
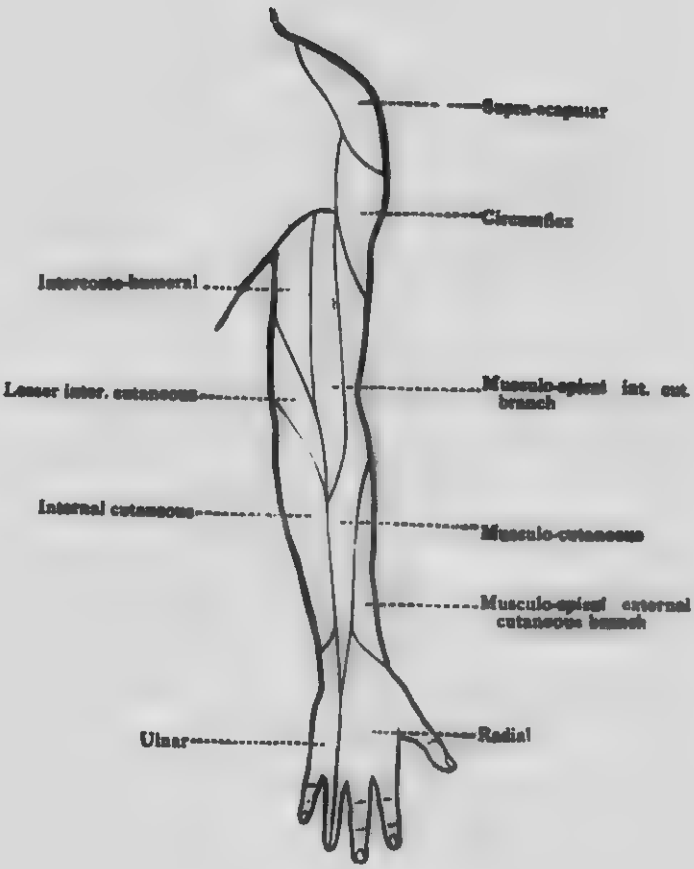

Peroneal n.
M. gastrocnem. external head
M. tibial. antic.
M. peroneus longus
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. extensor hallucis long.
M. flexor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VII.



Great occipital
Small occipital (cervical plexus)
Great auricular (cervical plexus)
5th. supra-orbital branch
5th. auriculo temporal branch
5th. infra-orbital branch
5th. inferior dental branch
Superficial cervical (cervical plexus)

PLATE VIII.



Supra-scapular
Circumflex
Intercosto-humeral
Lesser inter. cutaneous
Musculo-spiral int. cut. branch
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Ulnar
Radial

PLATE IX.

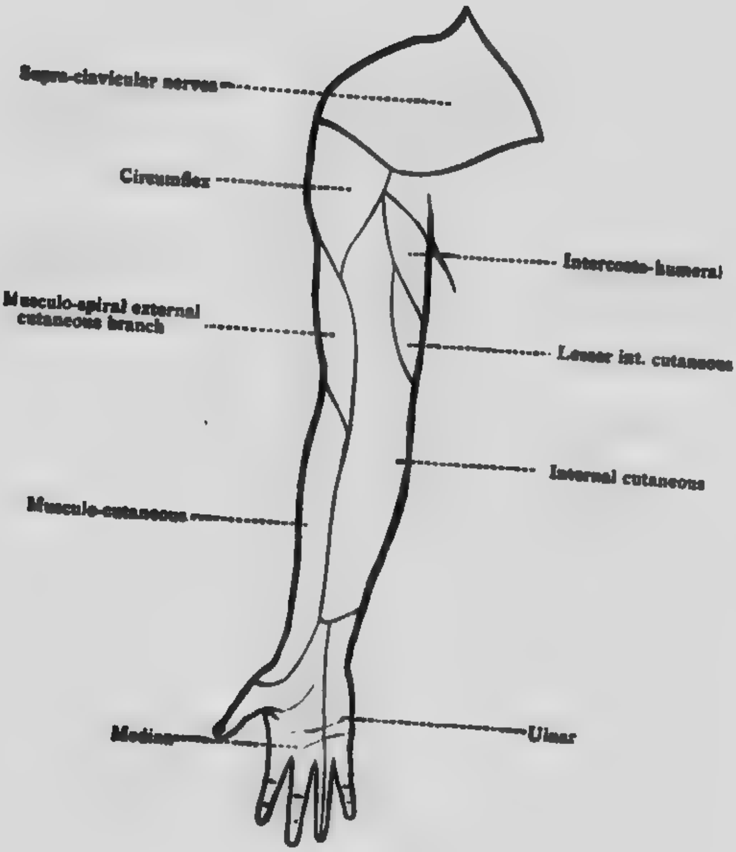

Supra-clavicular nerves
Circumflex
Intercosto-humeral
Musculo-spiral external cutaneous branch
Lesser int. cutaneous
Internal cutaneous
Musculo-cutaneous
Median
Ulnar

PLATE X.

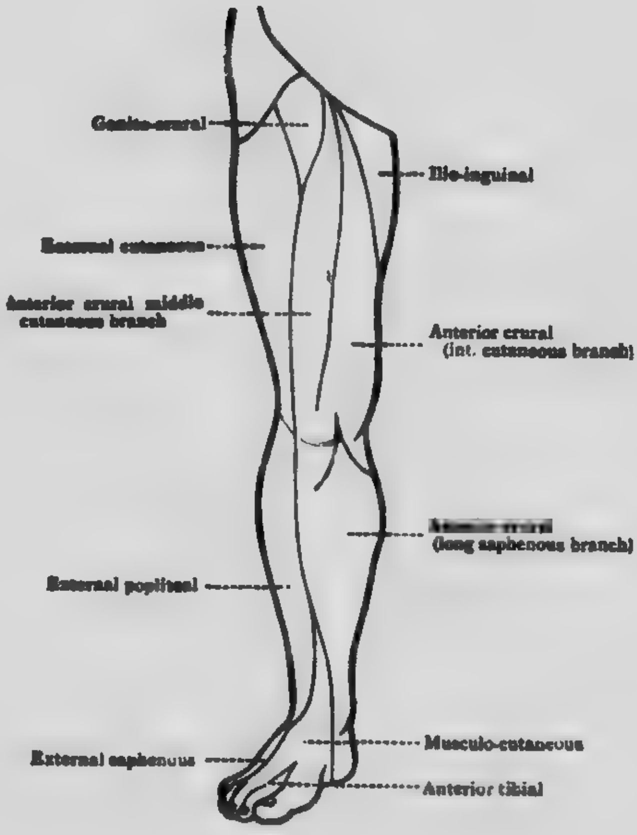
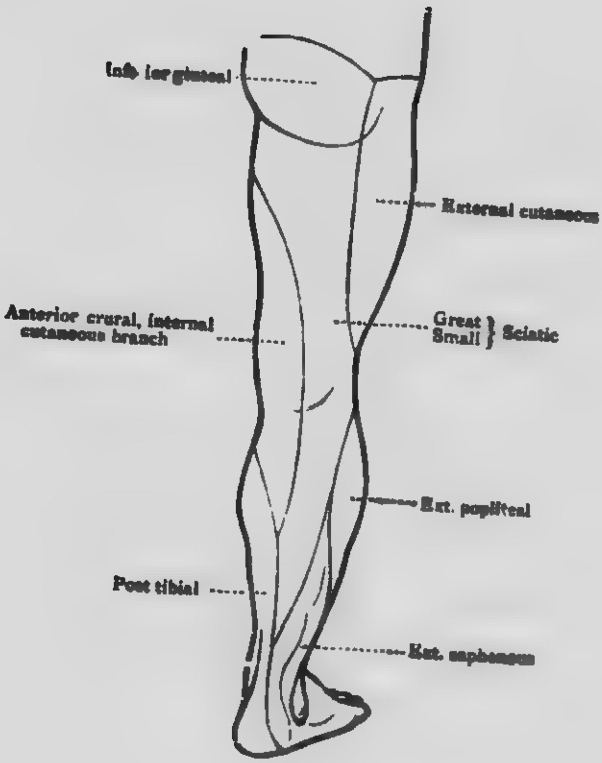

Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
[redacted] (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI.



Infe ior gluteal
External cutaneous
Anterior crural, internal cutaneous branch
Great
Small
Sciatic
Ext. popliteal
Post tibial
Ext. saphenous

PLATE XII.

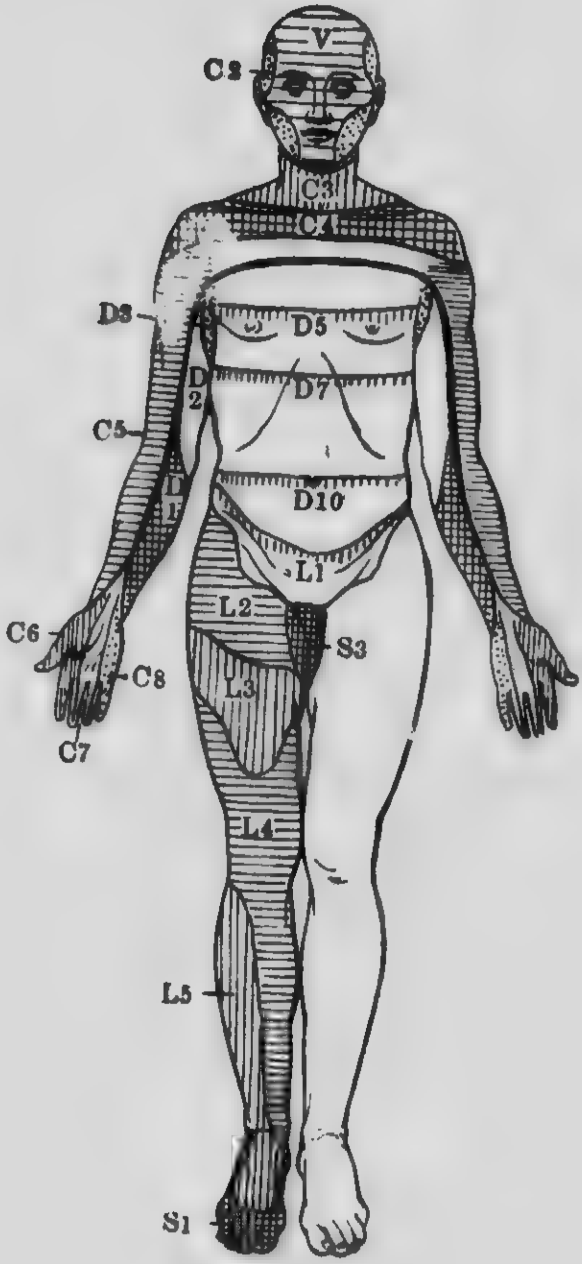


PLATE XIII.

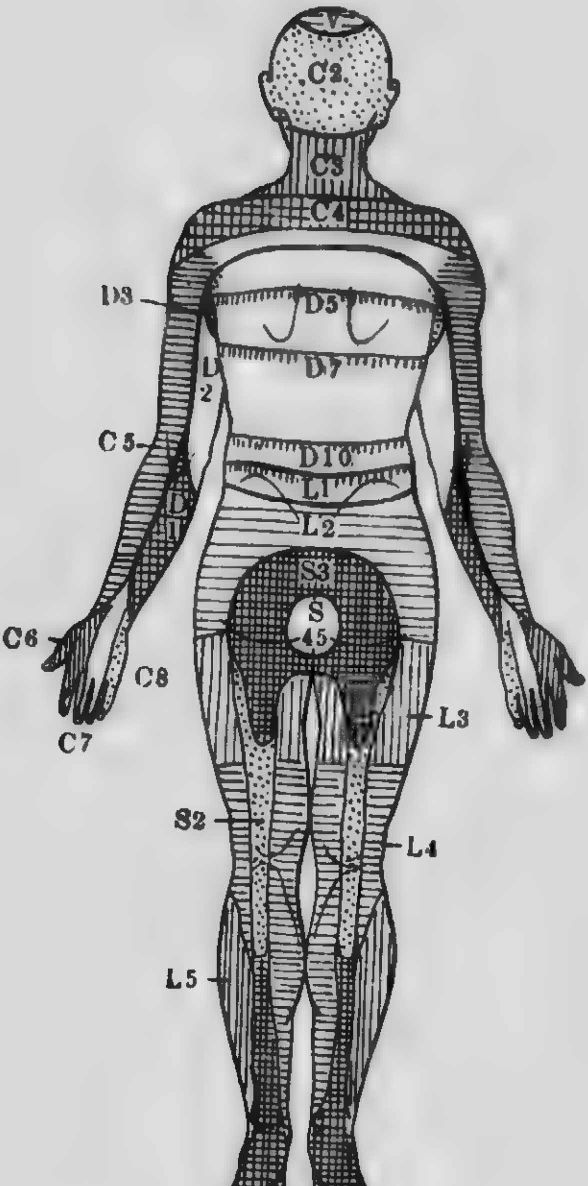
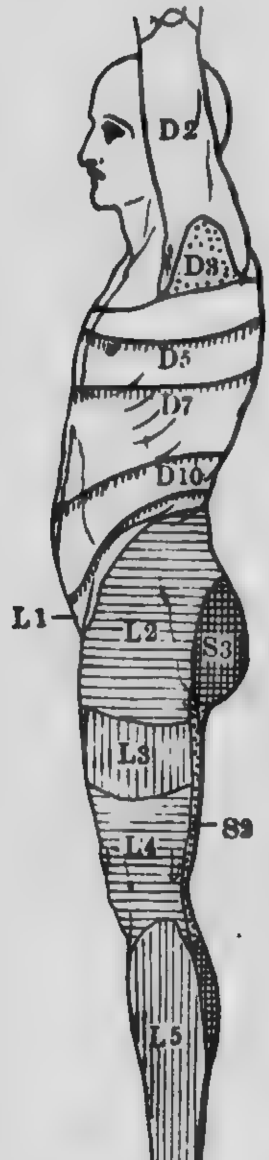


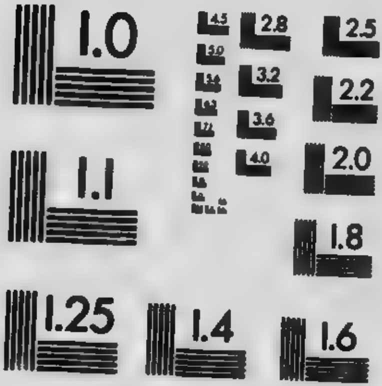
PLATE XIV.



INDEX

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc
1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

H. K. Lewis, 136, Gower Street, London, W.C.